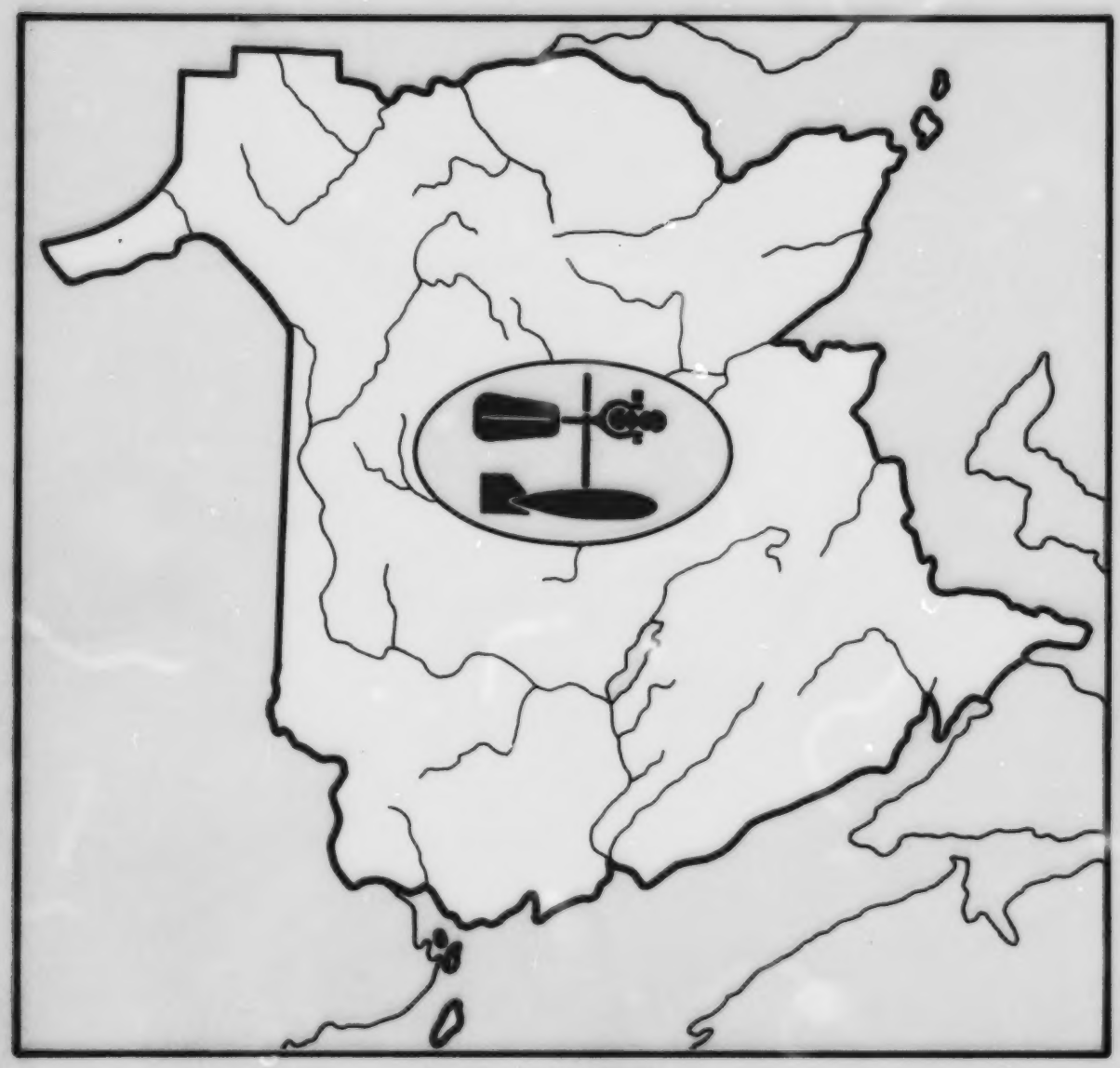
New Brunswick
Hydrometric Network Evaluation

Principal Report



December 1988

Environment Canada Environnement Canada

New Brunswick Department of Municipal Affairs and Environment

Ministère des Affaires Municipales et de L'Environnement du Nouveau-Brunswick

NEW BRUNSWICK HYDROMETRIC NETWORK EVALUATION

PRINCIPAL REPORT

Inland Waters Reference No. IWD-AR-WRB-88-142
Municipal Affairs and Environment Reference No. T88-01

Environment Canada
Conservation and Protection
Inland Waters
Dartmouth, Nova Scotia

New Brunswick Department of
Municipal Affairs and
Environment
Water Resource Planning Branch
Fredericton, New Brunswick

ABSTRACT

An evaluation of the hydrometric network in New Brunswick was performed starting from basic principles of hydrometric network design and proceeding through the analysis of the present network and its ability to meet user needs. Discharge stations used to monitor the streamflow component of the regional hydrology were assessed on their ability to contribute to the transfer of information to ungauged sites. A survey was conducted to determine users' needs. The results of the various analyses were combined using an audit approach based on selected rating factors. The final output includes specific network improvements designed to satisfy hydrometric needs and a list of network adjustment scenarios which are available as a management guide.

RESUME

Une evaluation du reseau hydrometrique du Nouveau-Brunswick fut entreprise debutant par les principes de base de conception d'un reseau hydrometrique et continuant par l'analyse du present reseau et de son abilite de repondre aux demandes des utilisateurs de donnees. Les stations hydrometriqe generant des debrits utilises pour faire des releves de l'hydrologie regionale furent evaluees pour leur contribution envers le transfer d'information aux sites non-jauges. Un sondage determina les demandes des utilisateurs de donnees. Les differentes analyses furent combinees dans un bilan base sur l'estimation de divers facteurs particuliers. Les resultats final se composent d'ameliorations specifiques de reseau dans le but de satisfaire les demands de donnees hydrologigues et d'une liste de scenarios possible futurs du reseau qui peuvant servir de guide aux gestionnaires.

TABLE OF CONTENTS

	Page
Title Page	-
Abstract/Resume	i
Table of Contents	ii
List of Figures	iv
List of Tables	vi
List of Contributors by Project Component	viii
EXECUTIVE SUMMARY(English/French)	x
1.0 CHAPTER ONE: INTRODUCTION	
1.1 Background	1
1.2 Overview of New Brunswick Hydrometric Network	1
1.3 Why Evaluate?	4
1.4 Project Overview and Scope	6
2.0 CHAPTER TWO: ASSESSMENT OF USER NEEDS	
2.1 General	8
2.2 User Survey Results	8
2.3 Other Identified User Needs	13
2.4 Summary	14
3.0 CHAPTER THREE: REGIONAL HYDROLOGY NEEDS	
3.1 General	16
3.2 A Minimum Regional Hydrology Network	16
3.3 A Target Regional Hydrology Network	25
3.4 Summary	30
4.0 CHAPTER FOUR: TECHNOLOGICAL AND OPERATIONAL ISSUES	
4.1 General	31
4.2 Emerging Trends	32
4.3 Summary	36
5.0 CHAPTER FIVE: EVALUATION OF GAUGING STRATEGIES	
5.1 General	37
5.2 A Supply/Demand Context	40
5.3 Cost-Benefit Considerations	43
5.4 A Pragmatic Approach	52
5.5 Audit Process	59
5.6 Audit Results	61
5.7 Summary	71

Page

6.0 CHAPTER SIX: MAIN FINDINGS AND RECOMMENDATIONS

6.1 General 73
6.2 Assessment of User Needs 73
6.3 Regional Hydrology Assessment 75
6.4 Hydrometric Technology and Operations 77
6.5 Evaluation of Gauging Strategies 77
6.6 Recommendations 79

Bibliography 83

Appendix A: Previous Hydrometric Network Reviews 92

Appendix B: Impacts of Alternative Gauging Strategies 96

Appendix C: List of Background Reports 112

LIST OF FIGURES

		Page
Figure 1.1	Length of Record	2
Figure 1.2	Size of Drainage Area	3
Figure 1.3	Existing Hydrometric Network	5
Figure 2.1	Respondents by Organization	10
Figure 2.2	Types of Hydrometric Data Required	11
Figure 2.3	Requirement for Interpreted Data by Organization	12
Figure 3.1	Climatic Regions of New Brunswick	17
Figure 3.2	Physiographic Subdivisions of New Brunswick	19
Figure 3.3	Physiographic-Climatic Zones of New Brunswick	20
Figure 3.4	Hydrologic Regions of New Brunswick	29
Figure 4.1	Water Resources Branch Electronic Data Acquisition System Configuration	34
Figure 5.1	Gauging Strategy Impacts on Network Objectives	67
Figure 5.2	Relative Benefits and Costs of Network Scenarios	70
Figure B.1	Existing Network	96
Figure B.2	Proposed Network 1	98
Figure B.3	Proposed Network 2	100
Figure B.4	Proposed Network 3	102

List of Figures Concluded

Figure B.5 Proposed Network 4 104

Figure B.6 Proposed Network 5 106

Figure B.7 Proposed Network 6 108

Figure B.8 Proposed Network 7 110

LIST OF TABLES

		Page
Table 2.1	User Survey Response	9
Table 2.2	Respondents Requiring Data	9
Table 2.3	Summary of Network Station Subsets	14
Table 3.1	Station Selections for Minimum and Target Regional Hydrology Network	22
Table 5.1	Uses of Hydrologic Information	46
Table 5.2	Operational Costs for New Brunswick Hydrometric Survey 1986-87	49
Table 5.3	New Brunswick Hydrometric Network	50
Table 5.4	Example of User Savings From a Regional Network	51
Table 5.5	New Brunswick Network Evaluation Station Audit	54
Table 5.6	Province-Wide Station Ranking by Station Audit Score	62
Table 5.7	Summary of Proposed Network Scenarios	69
Table B.1	Scenario Summary: Existing Network	97
Table B.2	Scenario Summary: Proposed Network 1	99
Table B.3	Scenario Summary: Proposed Network 2	101

List of Tables Concluded

Table B.4 Scenario Summary: Proposed Network 3 103

Table B.5 Scenario Summary: Proposed Network 4 105

Table B.6 Scenario Summary: Proposed Network 5 107

Table B.7 Scenario Summary: Proposed Network 6 109

Table B.8 Scenario Summary: Proposed Network 7 111

LIST OF CONTRIBUTORS BY PROJECT COMPONENT

COMPONENT	LEAD	OTHER CONTRIBUTORS	
Project Management	D. Ambler	--	
Summary Report	A. Perks Z. Davar D. Ambler B. Burrell	--	
Principal Report	Z. Davar D. Ambler	B. Burrell A. Perks	
Background Report #1	M. Sheeran	B. Burrell Z. Davar	A. Kendall G. Newell
Background Report #2	W. Brimley	J. Dublin	
Background Report #3	W. Brimley	D. Gingras B. Condie	D. Harvey
Background Report #4	B. Burrell	R. Lane K. Wiebe	
Roundtable Station Audit	Z. Davar	R. Lane J. Keefe B. Burrell W. Brimley D. Randall D. McBride	N. Elhadi D. Gingras D. Ambler T. Jones T. Humes A. Perks
Evaluation Framework, and Gauging Strategies	Z. Davar		
Supplemental Report	D. Ambler	J. Arbour D. Conrod M. Sheeran	B. Brimley D. Wilson Z. Davar

COMPONENT	LEAD	OTHER CONTRIBUTORS	
General Committee	D. Ambler	J. Arbour	J. Keefe
		D. Gingras	Z. Davar
		B. Brimley	A. Perks
		T. Jones	N. Elhadi
		B. Burrell	M. Sheeran
			S. Fenety

Other Contributors:

T. Jones(Project Proposal)
R. Howatt (Drafting)
S. Lake (Typing)
H. Pelkey (Short User Survey)
P. Belliveau (Water Quality Survey)
D. Wilson (Remote Sensing)

Summary Report on User Survey - Porter Dillon Limited,
N.C. Gridley,P.Eng.,
Project Manager

EXECUTIVE SUMMARY

An assessment of the hydrometric network in New Brunswick was carried out. User needs for data and information were identified and technical studies undertaken to define both a minimum level network as well as a target level capable of providing estimates of ungauged flows. These, together with assessments of the socio-economic conditions in the province and priorities for water resources management, were incorporated into a process of evaluating the relative contributions of individual stations, as well as the network as a whole.

The main findings of the project were that the network is quite highly "user-driven", with not enough attention given to meeting basic regional hydrology objectives. The user community, which includes various federal, provincial and private agencies makes frequent use of the data and receives a high level of direct benefit from the network. User perceived deficiencies included a lack of network coverage in central New Brunswick, a lack of small watershed data, and a desire for more interpreted information.

Technical studies yielded a definition of minimum needs for regional hydrology stations which, when compared against the existing network, confirmed the perceived deficiencies. Further studies indicated substantial uncertainties do exist in the ability to estimate ungauged streamflows in some areas.

A pragmatic evaluation process was developed and applied and served as a useful framework for integrating hydrological, socio-economic, and environmental factors. A ranked prioritization of stations based upon the best perceptions of station "worth" was developed. This will assist managers in making specific adjustments that may be required. Alternative network scenarios were also developed and assessed. These provide a basis for assessing the impact of changing resources or objectives for the program as a whole.

The major recommendations drawn from the findings are summarized below. The overall objective was to create a rationalized and more cost-effective network. This can be accomplished by:

establishing a Network Evaluation and Planning Subcommittee responsible for ongoing network analysis, communications with the user community, and preparation of an annual implementation plan for network adjustments, and integrated network planning with related data programs dealing with atmospheric conditions, water quality, and ground water.

using the results of this study to establish both short and long-term goals for the network. The short-term goal would be to ensure that the identified minimum network requirements are met through re-allocation of existing resources. The longer term goal would be to develop an enhanced regional hydrology capability as represented by the more comprehensive target network.

emphasizing the importance of regional hydrology needs in planning and operating the network, and assessing any tendency toward downsizing of the network against the potential loss in public savings and reduced service to the public.

pursuing integrated hydrologic network planning with the operators of related atmospheric, water quality, and ground water data programs.

working towards increased automation of the data collection activities.

implementing a marketing strategy designed to broaden the user base and increase the interaction and communication with users.

preparing more interpreted information designed to assist users and enhance the utility of the collected data for many applications.

RÉSUMÉ ADMINISTRATIF

Une étude du réseau hydrométrique du Nouveau-Brunswick a été effectuée. Les besoins des utilisateurs en matière de données et d'information ont été définis et des études techniques ont été entreprises pour définir un réseau d'un niveau minimum ainsi qu'un niveau cible pouvant fournir des prévisions sur les débits non jaugés. Ces mesures, ainsi que l'évaluation des conditions socio-économiques dans la province et des priorités pour la gestion des ressources en eaux, ont été intégrées à l'évaluation de la contribution relative des stations individuelles et du réseau en général.

Le projet a permis de constater principalement que le réseau est gradement axé sur "les utilisateurs", et qu'on n'accorde pas suffisamment d'attention aux mesures à prendre pour répondre aux objectifs hydrologiques régionaux de base. Les utilisateurs, soit divers organismes fédéraux, provinciaux et privés, emploient fréquemment les données et reçoivent un niveau élevé de services directs du réseau. Les lacunes perçues par les utilisateurs comprennent un manque de services offerts par le réseau au centre du Nouveau-Brunswick, un manque de données sur les petits bassins hydrographiques; ils souhaiteraient aussi avoir plus de données interprétées.

Les études techniques ont produit une définition des besoins minimums relatifs aux stations hydrolgiques régionales qui, une fois comparée à ceux du réseau actuel, a confirmé les lacunes perçues. D'autres études ont révélé qu'il existe des incertitudes importantes par rapport à la capacité de mesurer les débits des cours d'eau non jaugés dans certaines régions.

Un processus d'évaluation pragmatique a été mis au point et appliqué; il a servi de cadre valable pour intégrer les facteurs environnementaux, socio-économiques et hydrologiques. On a établi un système de classement par priorité des stations fondé sur la meilleure perception de leur valeur. Ce système aidera les gestionnaires à effectuer les rajustements particuliers qui pourraient s'avérer nécessaires. On a dressé et évalué également d'autres scénarios de réseau. Ceux-ci constituent une base pour déterminer les effets des ressources ou des objectifs en constante évolution sur le programme en général.

Les principales recommendations fondées sur les constations sont résumées ci-dessous. L'objectif global était de créer un réseau rationalisé d'un meilleur rapport efficacité-coût. Cet objectif peut être réalisé par les moyens suivants:

en établissant un sous-comité de planification et d'évaluation du réseau chargé de l'analyse continue de ce dernier, des communications avec les utilisateurs, de la préparation d'un plan annuel de mise en oeuvre pour les rajustements du réseau ainsi que de la planification d'un réseau intégré relativement aux programmes de données sur les conditions atmosphériques, la qualité de l'eau et les eaux souterraines.

en utilisant les résultats de cette étude afin d'établir des objectifs à long terme et à court terme pour le réseau. L'objectif à court terme serait d'assurer que les besoins minimums identifiés du réseau soient comblés par le réaménagement des ressources actuelles. L'objectif à long terme serait de développer une capacité hydrologique régionale accrue représentée par le réseau cible plus global.

en soulignant l'importance des besoins hydrologiques régionaux dans la planification et le fonctionnement du réseau, et en évaluant toute tendance vers la réduction de celui-ci contre la perte éventuelle d'économies publiques et la réduction des services à la population.

en poursuivant la plantification du réseau hydrologique intégré en collaboration avec les exploitants des programmes connexes de données sur les eaux sourterraines, la qualité de l'eau conditions atmosphériques.

en travaillant en vue de l'informatisation des activités de cueillette des données.

en mattant en oeuvre une stratégie de promotion visant à élargir la base des utilisateurs et à accroître l'interaction et la communication avec ces derniers.

en préparant plus de données interprétées afin d'aider les utilisateurs et d'accroître l'utilité des données recueillies pour de nombreuses applications.

1.0 INTRODUCTION

1.1 BACKGROUND

The network of hydrometric gauging stations in New Brunswick provides the basic water quantity data and information necessary for most hydrologic and water management activities in the Province. The goal is to ensure that the data collected and analyzed meets the needs of the user community and does so in the most cost-effective manner. In order to achieve this goal, the network must be designed so as to meet the needs for current, site-specific data while at the same time maintain a basic inventory network from which reasonable hydrologic projections can be made.

A previous review of the hydrometric network in New Brunswick was done in 1979 leading to recommendations for improvements. A number of the recommendations were implemented, while others remain to be implemented. In 1985, a review of the network from both hydrologic and socio-economic aspects was commissioned by the Federal-Provincial Co-ordinators. This report, the Summary Report, the Supplemental Report and the four technical Background Reports present the findings of this joint Federal-Provincial study.

1.2 OVERVIEW OF NEW BRUNSWICK HYDROMETRIC NETWORK

Many water resources issues, ie. hydro power, have required the installation of hydrometric stations leading to the present network made up of 83 stations. Today's network includes 54 natural regime stations and 31 regulated regime stations. Data from two additional stations are contributed to Environment Canada for publication. The total network of 85 stations contains six stations where sediment data are concurrently collected. Real-time, within 8 hours, data transmission is available at 41 stations which includes 8 satellite data transmission stations and 33 telephone data transmission stations.

Figure 1.1 shows the temporal distribution of the current network. The current network ranges from one station with over 66 years of record to eight stations with less than five years of record. Eight stations have records covering 56 to 70 years while 11 stations have 26 to 56 years of record. The largest group, 66 stations, have from less than five years to 25 years of record.

Figure 1.2 displays the spatial distribution of the flow stations. This group totals 66 and does not include the 17 water level stations. From this Figure it can quickly be seen that

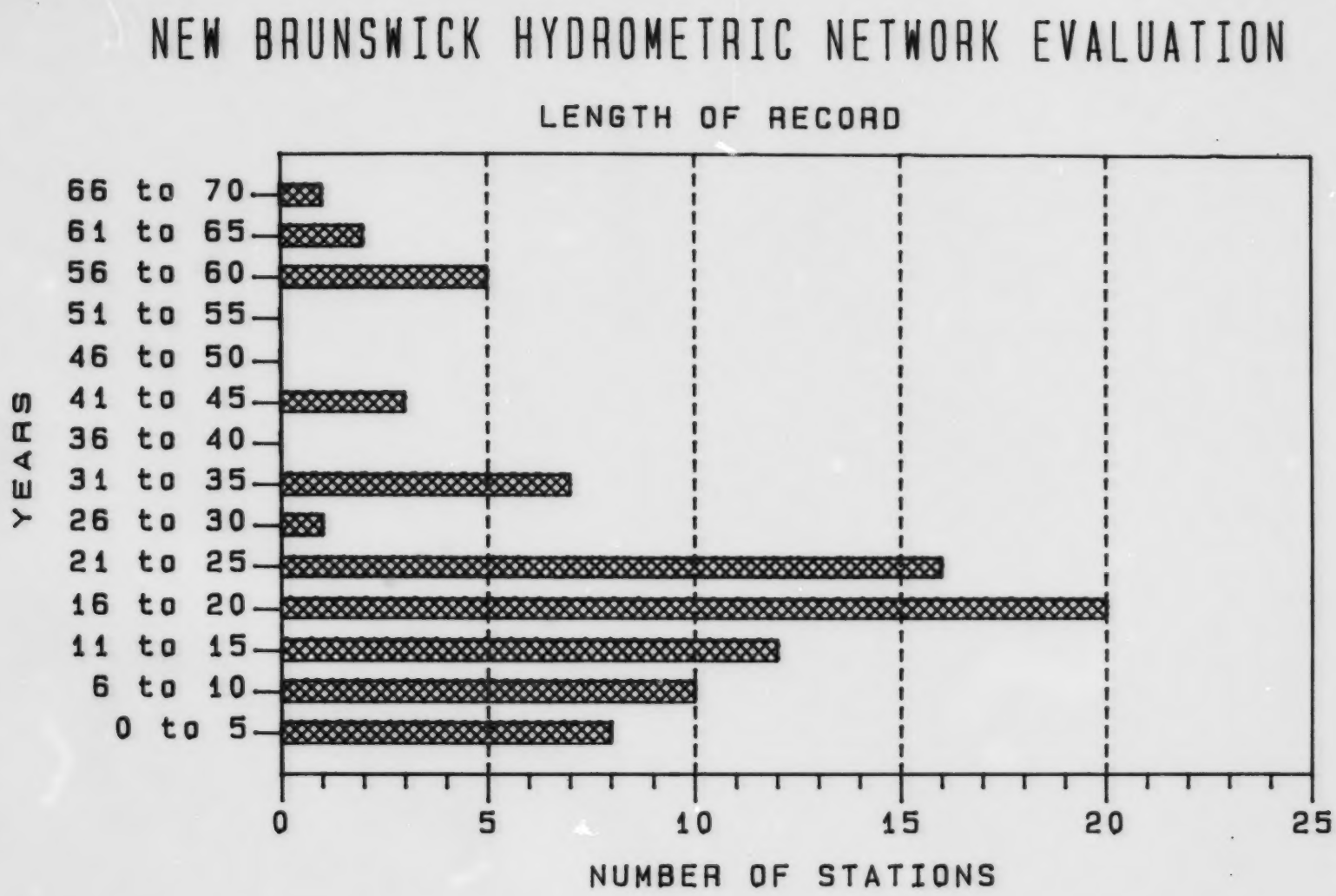


Figure 1-1 Length of Record

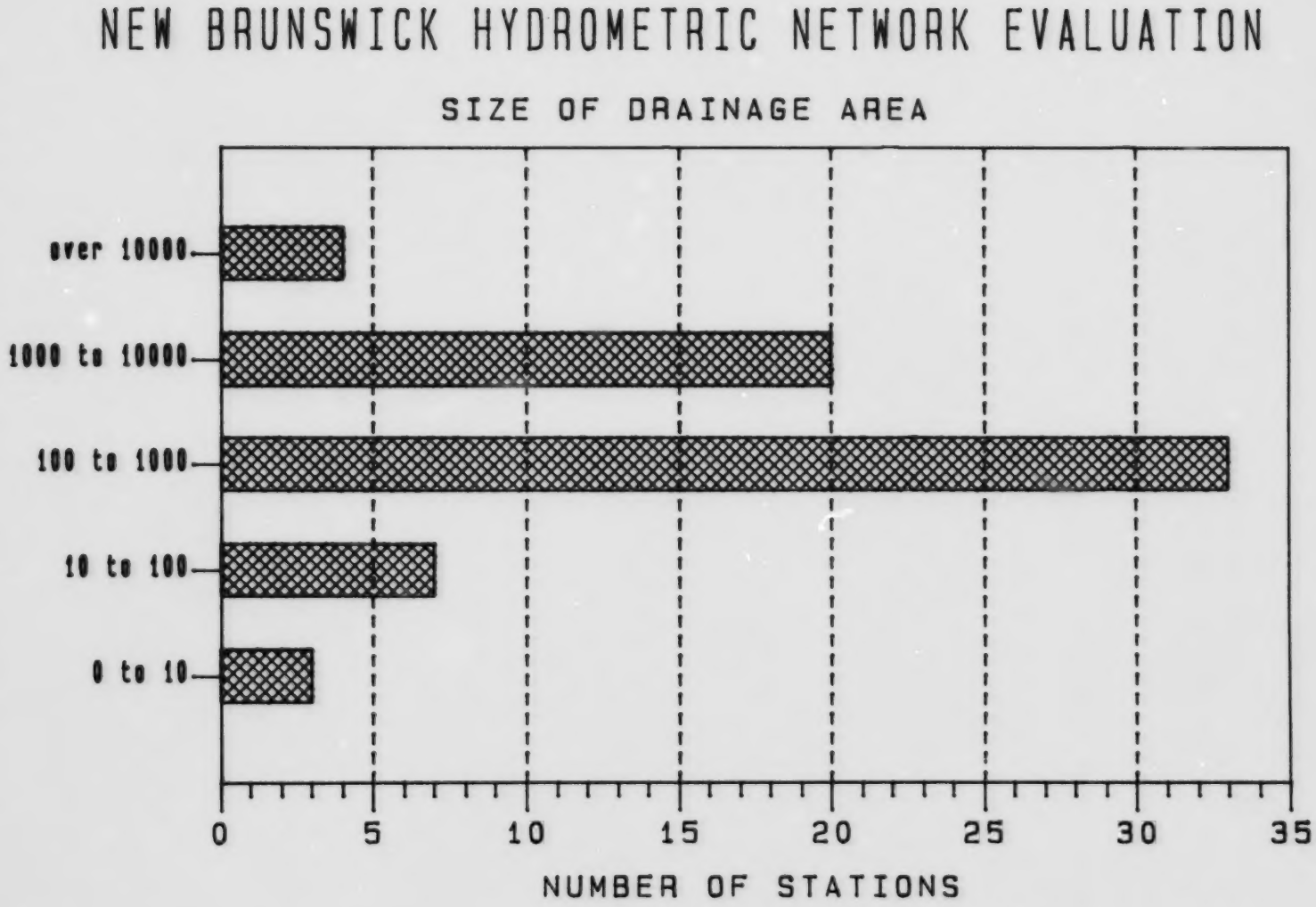


Figure 1-2 Size of Drainage Area

three gauges monitor drainages over 10,000 sq. km. followed by 20 stations in the 1,000 to 10,000 sq. km. range. The bulk of the network, 33 stations, monitor basins in the 100 to 1,000 sq. km. range. The coverage of small drainages is very limited, with 7 gauges in the 10 to 100 sq. km. range and only 3 gauges monitoring areas less than 10 sq. km.

The existing network in New Brunswick is shown in simple outline form in Figure 1.3.

1.3 WHY EVALUATE?

"The major problem that forces one to a consideration of efficiency or cost-effectiveness is the potential of the cost of neglect, benign or not, to over collect in various ways to the neglect of observations that may prove to be of greater need...Data programs are usually found to be too ambitious and inadequate at the same time" (Langbein 1979).

This paradoxical observation reflects the concern that in the absence of proper planning and evaluation, an information network or system may tend to develop both redundancies and gaps in the knowledge base.

Potential examples include: intensive on-going measurement in areas of previous historical importance at the expense of deficient information for developing areas; over-emphasis on large basins at the expense of poor understanding of small basin hydrology; over-gauging of highly correlated contiguous sites with insufficient information at other neglected sites; and gauging to meet those needs for which estimations would suffice.

The evaluation methodology employed in this study is based on a cost-effectiveness framework. Cost-effectiveness criteria typically take one of two forms: maximization of outputs or benefits within a given budget constraint; or minimization of cost for a given level of output or benefits. The former is more appropriate to this case. Maximization of benefits will be regarded as maximization of the 'worth' of the network's outputs (worth being defined in terms of the output's utility to users). With unconstrained resources, worth can be maximized (measurement error aside) simply by gauging every stream in the Province. However, the use of data transfer techniques enables the provision of equivalent worth by gauging only representative streams. Furthermore, consideration of the availability of resources imposes a constraint on the level of worth attainable, thereby requiring that priorities be determined for network outputs.

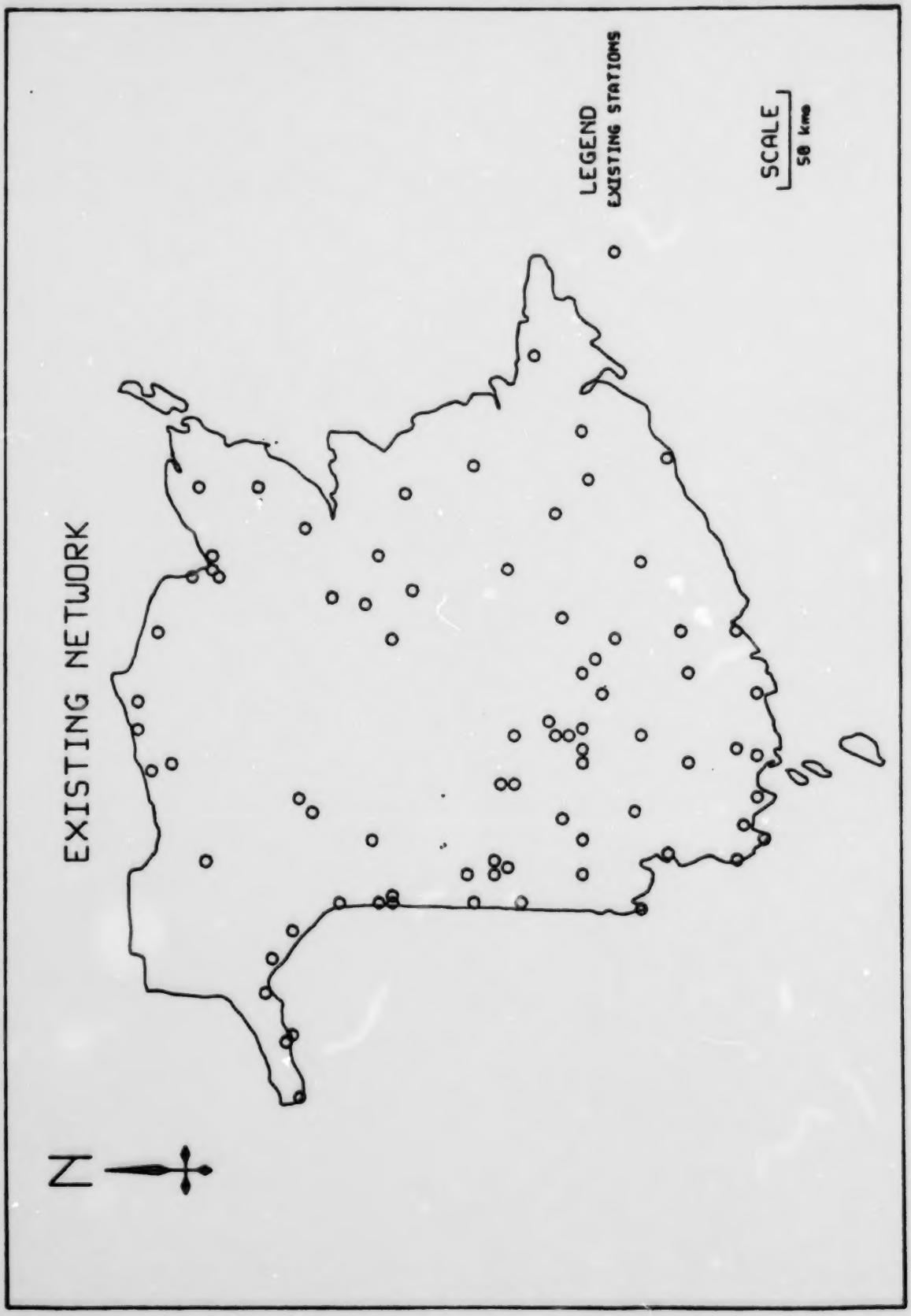


Figure 1-3 Existing Hydrometric Network

This determination of priorities will provide three key management tools:

- a rationale for re-allocating existing resources from lower to higher priorities;

- an ordering of priorities for allocation of additional resources; or

- an ordering of priorities for an imposed reduction of resources.

1.4 PROJECT OVERVIEW AND SCOPE

Expansion of the New Brunswick network accelerated during late 1960's and early 1970's with the increased demand for information for water supply, fisheries and flood forecasting purposes. Many stations were established to meet specific user needs, sometimes of a short-term nature. Many of these stations which had served their original purpose were retained in order to secure a longer and statistically more useful period of record. At that time, this was considered an effective method of expansion, as the network was sparse and the initial capital and operating costs for establishing the station had already been paid.

This historical expansion path has led to the present "collection" of regional hydrology and operational gauging sites, which is deficient in respect to certain network objectives, though at the same time redundant in others.

In an attempt to rationalize the network, user needs for data and information were firstly identified by conducting mail-out and personal contact surveys. The details of the user survey are found in the Background Report Number 1, "Assessment of User Needs" and the main findings are discussed in Chapter Two of this report.

A number of methodologies were investigated to establish network criteria for regional hydrology purposes. A suggested "minimum" coverage was determined based on physiographic-climatic zones as the representative hydrologic units, as well as a "target" or "optimal" network based on hydrologic regions for which relationships could be defined for estimations at ungauged sites. Background Reports Number 2, "Delineation of Physiographic-Climatic Zones" and Number 3, "Regional Hydrology and Data Transfer Methodologies" give the details of these studies. The findings are summarized in Chapter Three of this report. Background Report Number 4, "Selected Technological and Operational Issues" was undertaken to investigate the technical and operational issues of importance to the ongoing operation of the network in a cost-effective manner. The findings of the report are summarized in Chapter Four of this report.

In Chapter 5, the regional hydrology criteria were subsequently input to the development of an evaluation framework which additionally incorporated the consideration of user needs and cost-effectiveness criteria. The evaluation framework, which utilizes an audit approach to assess the relative contributions of both existing and proposed stations to specified network objectives, attempts to circumvent the conceptual hurdles involved in typical rigorous procedures for optimization.

Finally, a number of alternate network scenarios were identified, applying a range of budget levels to the prioritized ordering of stations, and focussing on varying objectives ranging from minimum delivery of a "public good" mandate to all-inclusive delivery of identified needs including an "optimal" regional hydrology network.

The main findings and recommendations of the project are presented in Chapter Six.

2.0 ASSESSMENT OF USER NEEDS

2.1 GENERAL

A user survey in conjunction with other information, provided the background for assessment of hydrometric data user needs. Table 2.1 presents the response rate achieved. Table 2.2 itemizes the respondents requiring hydrometric data by organization type. Background Report No. 1 provides a detailed analysis of the results of the survey and other sources of information on users' needs. A summary is presented here.

2.2 USER SURVEY RESULTS

Government agencies, engineering/environmental consultants, hydro-electric power utilities, and academic institutions were found, not unexpectedly, to be the foremost users of hydrometric data for both design and operational purposes. Industry, food and beverage companies, and fish and game organizations had a considerably lower requirement for network data, possibly from either a lack of awareness of network outputs, or having a requirement for a data product with a higher level of interpretation such as fact sheets. Figure 2.1 shows the relative responses by each type of organization; while the types of data required are shown in Figure 2.2, and the requirement for interpreted data by organization type is shown in Figure 2.3.

The results of the user needs survey also indicated that:

1) there was low awareness of Water Resources Branch publications among non-professional users;

2) approximately half the data users were willing to pay at least a nominal fee for data provided;

3) of the respondents indicating a desired level of accuracy for data produced through data transfer techniques, 85% required high quality information with a $\pm$ 20% accuracy; and

4) there was frequent use of data (at least once a month) by approximately 90% of the respondents to the "Long-Form".

TABLE 2.1

USER SURVEY RESPONSE

Form	Number Sent	Number Completed	Rate	Survey Method
Short	385	139	36%	Mail Out
Long	132	124	94%	Interviewed by phone or in person
TOTAL	517	263	51%	

TABLE 2.2

RESPONDENTS REQUIRING DATA
(TOTAL = 146)

Percent Respondents Requiring Data	Type of Organization
35	Government Agencies
21	Consultants
14	Municipalities
14	Industries
7	Fish & Game Organizations
4	Academic Institutions
3	Utilities
2	Food & Beverage Companies
100	

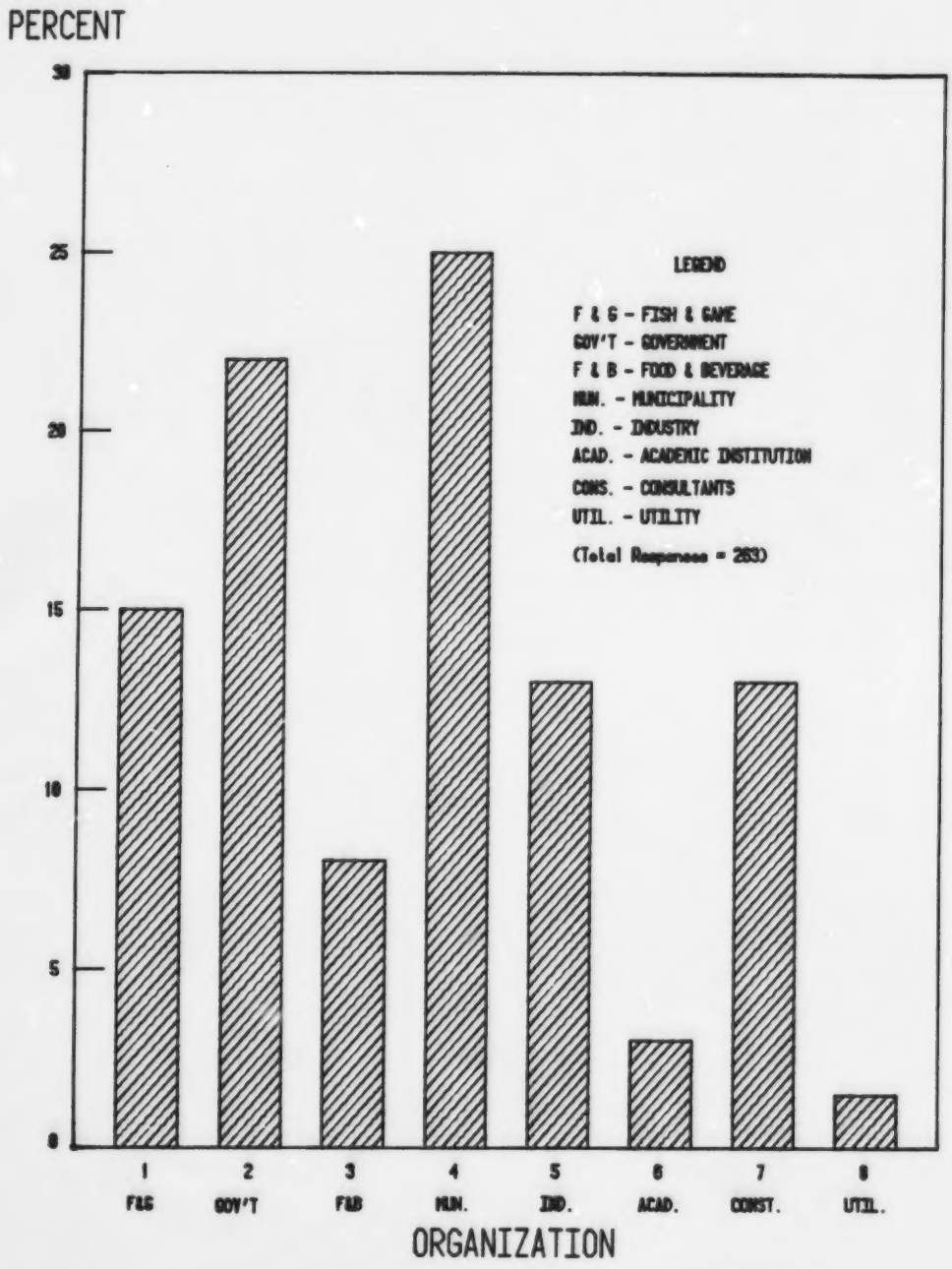


Figure 2-1 Respondents by Organization

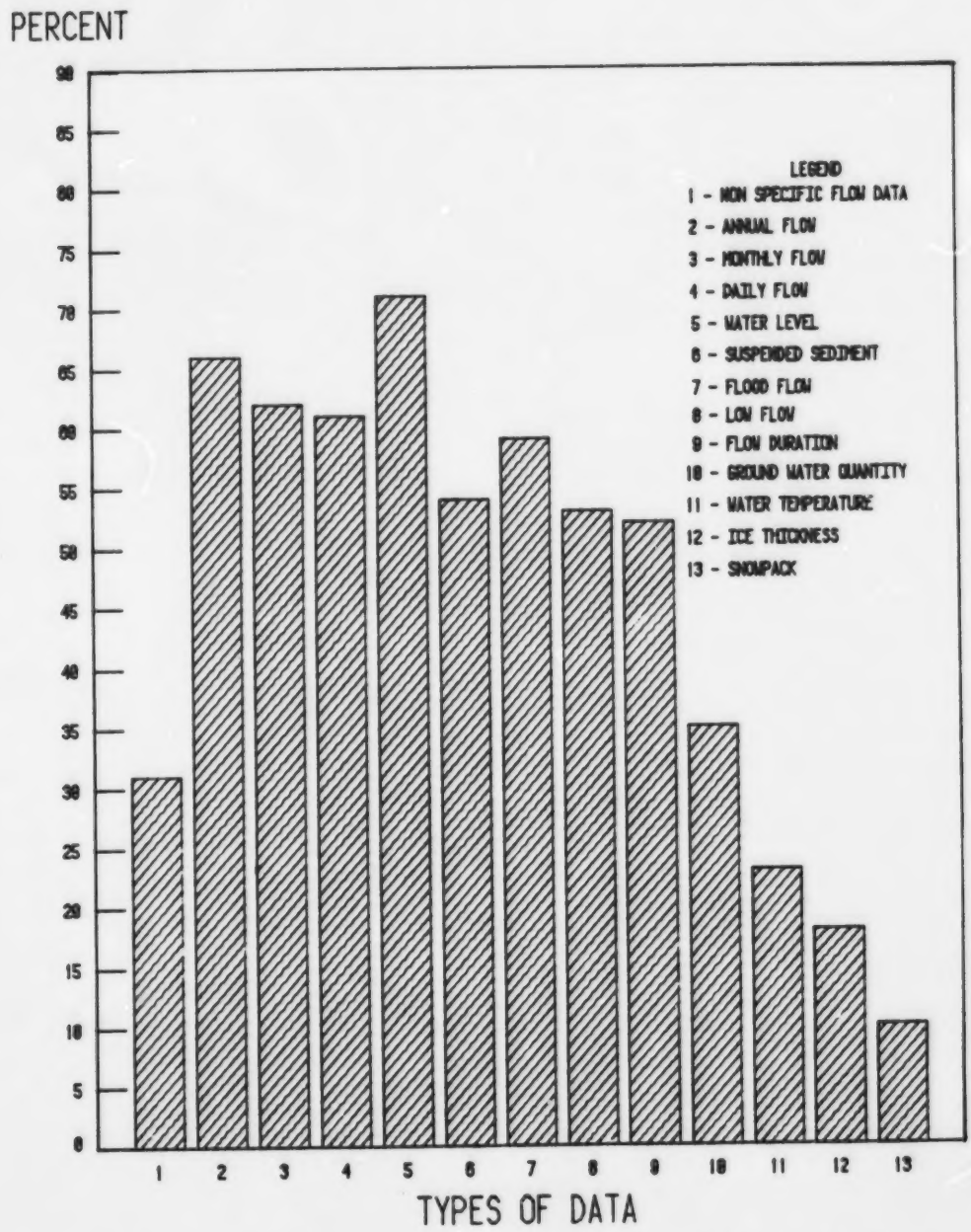


Figure 2-2 Types of Hydrometric Data Required (Percent of Respondents Requiring Data)

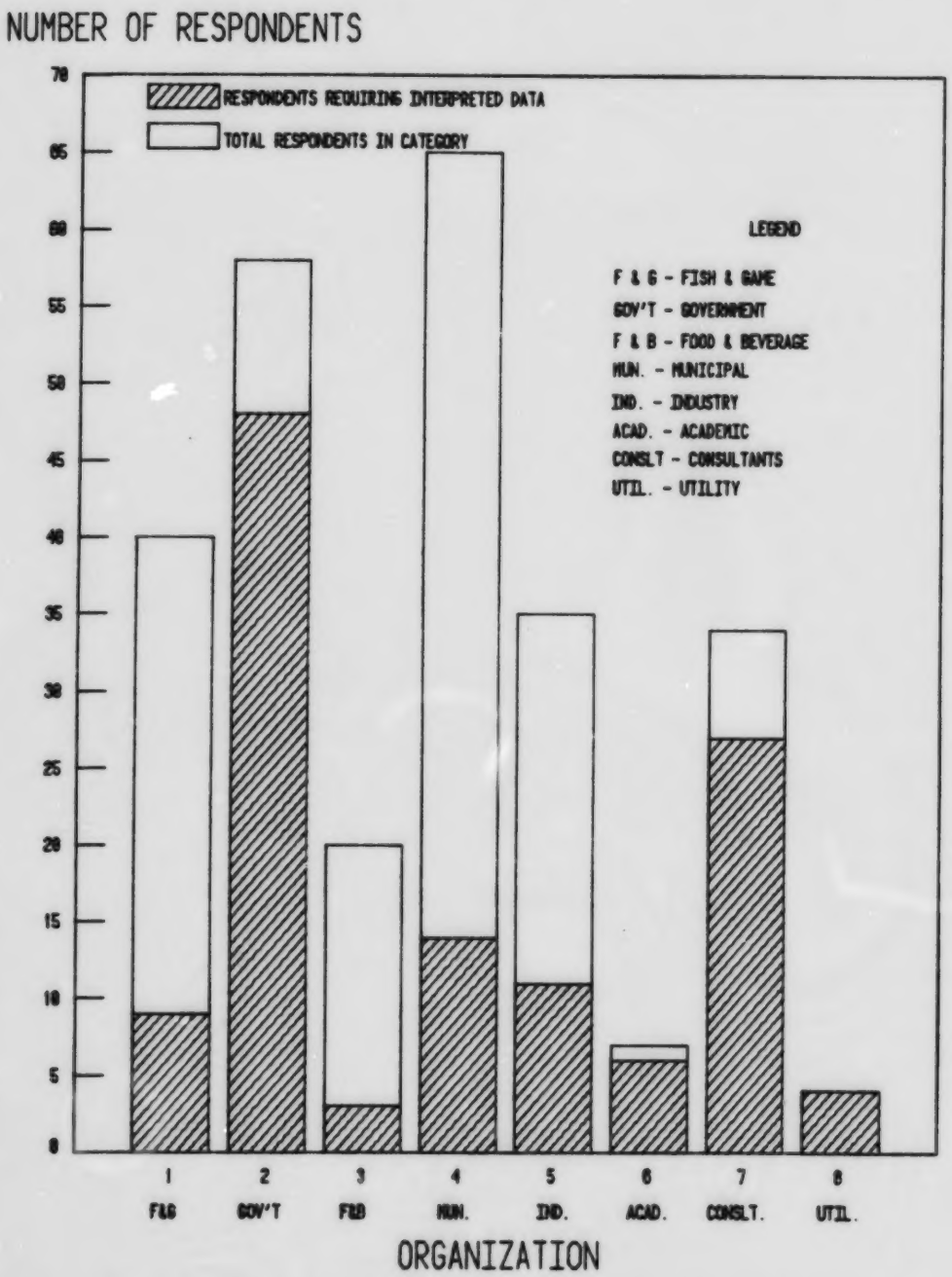


Figure 2-3 Requirement for Interpreted Data by Organization

Some data users indicated deficiencies with the hydrometric network in the following areas:

1) station coverage in central New Brunswick;

2) lack of index stations in small watersheds; and

3) the accuracy in data transfer techniques.

Some other users suggested integration of networks (eg. Atmospheric Environment Service (AES), water quality, and water quantity) and cross-linking databases (eg. precipitation, ice, water level and flow data) to facilitate data retrieval and analyses. Others suggested that there be greater emphasis on data interpretation than there is currently.

The user survey was useful in gaining an assessment of regional hydrology needs. It, however, did not succeed in obtaining information regarding data requirements specific to gauging stations. Generally, the most informative responses came from people who had been interviewed personally or by telephone since the interviewer could explain the questions when necessary and guide the respondent through the questionnaire.

2.3 OTHER IDENTIFIED USER NEEDS

Further information regarding user needs specific to gauging stations was obtained from discussions aimed at assessing the relative importance of each existing and proposed network station. This exercise, with participants from the respective federal and provincial water resource agencies, was termed the "Round Table Station Audit". Table 2.3 summarizes the principal requirements for station-specific data. The most significant are for regional hydrology, flood forecasting and related studies, and fisheries.

TABLE 2.3

SUMMARY OF NETWORK STATION SUBSETS*

Purpose	Number of Stations Used
Regional Hydrology	62
Flood Forecasting and Related Studies	49
Fisheries	31
Environmental Impact	26
Energy	25
Navigation & Recreation	18
Water Supply	17
Other Investigations	17

* Total number of stations = 85
(stations may belong to more than one subset.)

2.4 SUMMARY

Government agencies, engineering/environmental consultants, hydroelectric power utilities, and academic institutions had the greatest need for hydrometric data for both regional hydrology and operational purposes. Data used for operational purposes were required for activities related principally to flood forecasting and power generation in the Saint John River Basin. It was also found that there was low awareness of Water Resources Branch publications among non-professional users.

Approximately half of the data users were willing to pay at least a nominal fee for data provided. They made frequent use of hydrometric data and required quality information ($\pm$ 20% accuracy).

Respondents to the user survey provided generalizations about their data requirements rather than being site specific. This made it necessary to infer their station-specific data needs. In view of this, a Data User Workshop, with representatives from Environment Canada, Water Resources Branch; New Brunswick Department of Municipal Affairs and Environment, Water Resource Planning Branch; and principal data users should be held periodically to hold a series of round-table discussions to more accurately determine data users' needs on a station-by-station basis.

3.0 REGIONAL HYDROLOGY NEEDS

3.1 GENERAL

The primary function of a regional hydrology network is to sample representative basins in a given region so that hydrologic characteristics at ungauged locations can be estimated for a variety of planning and design applications. The selection of gauging stations to represent a region is critical and should reflect the full range of basin sizes and physiographic-climatic conditions that exist in the region. A number of methodologies were investigated to establish selection criteria. A suggested "minimum" coverage was determined based on physiographic-climatic zones as the representative hydrologic units, as well as a "target" network based on hydrologically defined regions for which statistical estimations could be provided at ungauged sites.

3.2 A MINIMUM REGIONAL HYDROLOGY NETWORK

3.2.1 Determination of Physiographic-Climatic Zones

Climate, physiography and land use data were classified in ranges of characteristics and combined to form representative zones. The expectation was that within each such zone the streamflow characteristics should, on average, be similar enough to be analysed as a homogeneous hydrologic unit. By using this approach, it is possible to identify areas which are either inadequately or over-represented by the present network.

The main driving force of regional hydrology is the regional climate. Runoff varies directly with precipitation. Other factors such as the storage and melting of snow are also seasonally important factors.

Figure 3.1 delineates four, more or less, homogeneous climatic regions for New Brunswick using as the main parameters for classification: average annual precipitation, average annual snowfall and the average water equivalent of the snowpack on March 31st of each year. Note, these boundaries should not be considered absolute since there are usually gradual changes in climate except where the boundaries and significant changes in topography coincide.

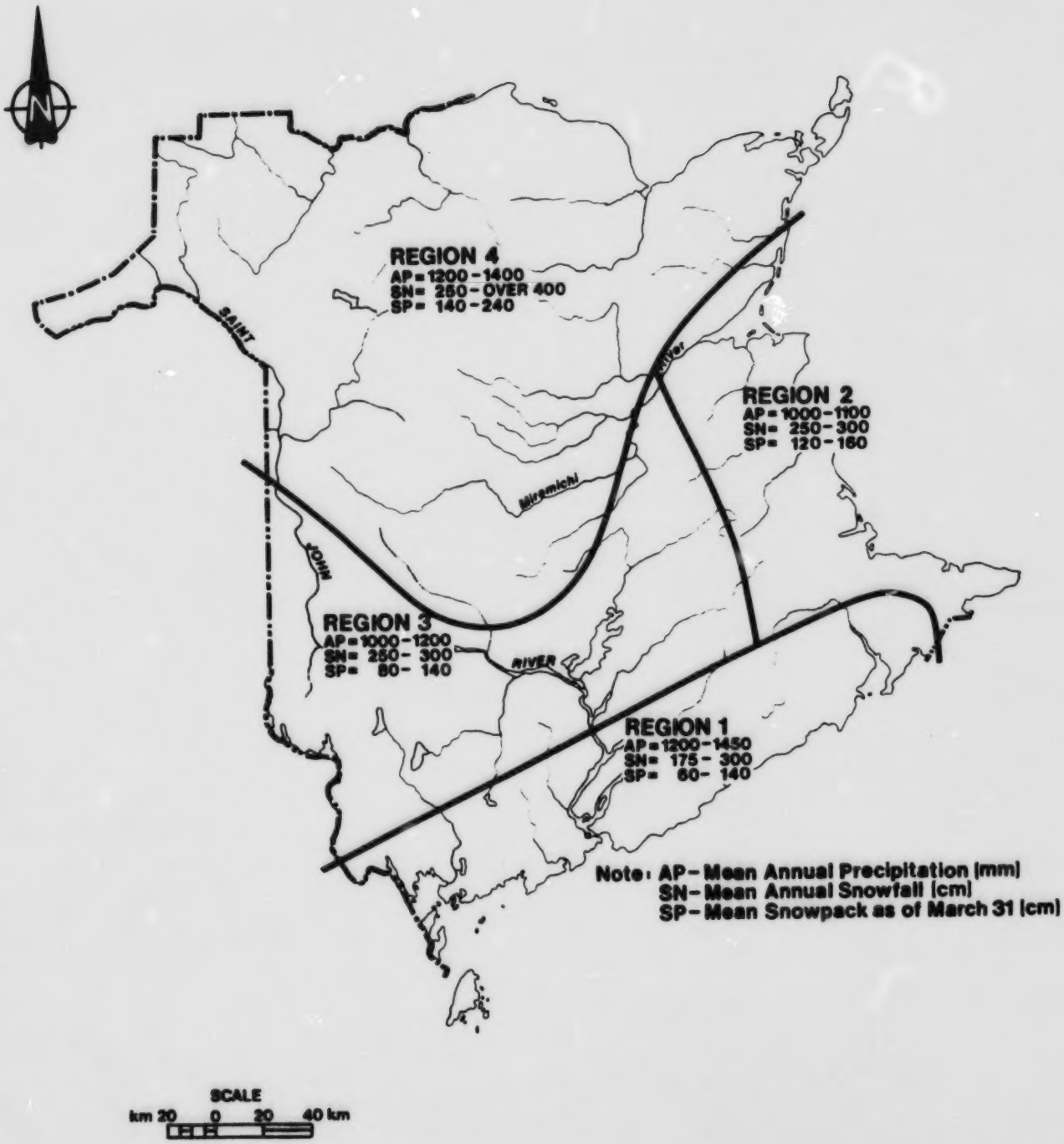

N
REGION 4
AP = 1200 - 1400
SN = 250 - OVER 400
SP = 140 - 240
REGION 2
AP = 1000 - 1100
SN = 250 - 300
SP = 120 - 160
REGION 3
AP = 1000 - 1200
SN = 250 - 300
SP = 80 - 140
REGION 1
AP = 1200 - 1450
SN = 175 - 300
SP = 60 - 140
SAINT
JOHN
RIVER
Miramichi
Note: AP - Mean Annual Precipitation (mm)
SN - Mean Annual Snowfall (cm)
SP - Mean Snowpack as of March 31 (cm)
SCALE
km 20 0 20 40 km

Figure 3-1 Climatic Regions of New Brunswick

Topography, which is a function of the underlying bedrock geology and the overlying surficial deposits, is the most important mechanism acting on any precipitation which exceeds the infiltration capacity of the soil (ie. direct runoff). Based on such topographic parameters as slope and pattern and efficiency of drainage, the physiographic divisions of New Brunswick have been defined (Bostock, 1970) and revised by Rampton et al. (1984) and are shown in Figure 3.2

Subsequently, the Canada Land Use Management Program (CLUMP) database was overlayed with basin delineations to incorporate land use considerations. A summary of the data showed that approximately 85% of the province is covered by forest. Areas which showed the proportion of marshland greater than 5% or agricultural lands greater than 10% of the drainage area were used to help in the delineation of the zone boundaries.

Finally, fifteen physiographic-climatic zones were determined by overlaying the physiographic, climate and land use mosaics and dividing them along their intersections. The divisions are shown in Figure 3.3. Zone 16, although in the State of Maine, was included for completeness because of its impact on the upper Saint John River. Zones were typically delineated along the nearest basin divide, if the intersections were close to the divide. The main exceptions were the Saint John River main stem, the Restigouche River, and the Southwest Miramichi River, where physical changes were noted between the zones through which these major rivers flow.

3.2.2 Minimum Criteria and Station Selection

Ideally, each physiographic-climatic zone should contain a sufficient mix of natural flow stations to portray the hydrologic characteristics of the zone. No rigorous rules currently pertain to the number or distribution of the stations in a zone although some guidelines have been proposed such as the World Meteorological Organization (1974) guidelines on minimum networks. Comparing the number of existing stations suitable for regional hydrology with those proposed by the WMO criteria, it was noted that the present network is less than minimum under these guidelines, in all but a few zones. Furthermore, it was felt that the WMO guidelines do not provide for sufficient representation in those zones which have a wide range of drainage areas.

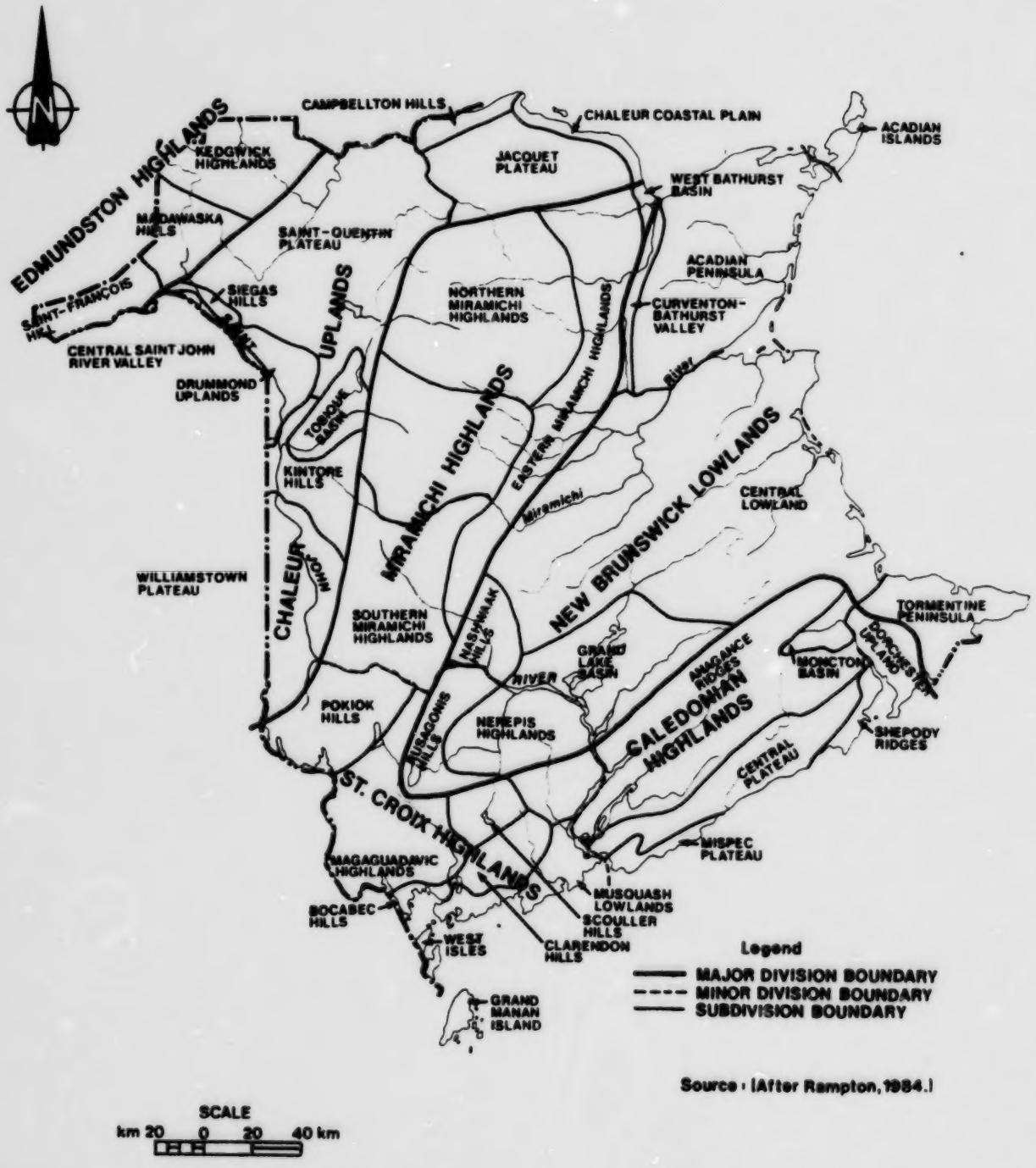


Figure 3-2 Physiographic Subdivisions of New Brunswick

SCALE
km 20 0 20 40 km

Figure 3-3 Physiographic-Climatic Zones of New Brunswick

The first step in the selection of representative streams for the minimum natural flow network was to identify major rivers whose drainage areas crossed a multiple of zones.

Subsequently, a strict minimum sample of one large, one medium and one small stream in each zone was established. Some zones were regarded as more complex than others in terms of their physiography and their range in stream size and were allocated an increased sample size.

Based on these criteria, a Minimum Regional Hydrology Network was selected and is shown in Table 3.1. This Minimum Network comprises 54 stations, only 37 of which are found in the existing network. That is, 17 newly created stations would be required to satisfy the criteria identified here for minimum regional hydrology coverage. Of these, 9 would be required on small basins (less than 100 km^2).

It is cautioned that the Minimum Network identified above cannot, however, be regarded as anything more than a collection of stations assumed to represent areas of relatively homogeneous hydrologic characteristics. It has been developed from intuitive principles and has insufficient sample size to test for statistical significance. Furthermore, the variation in basin sizes within zones renders even simple proration as suspect for accurate data transfer. As such, the Minimum Network constitutes a "least credible" capability for the provision of regional hydrology information for the Province.

Table 3.1

Station Selections for Minimum and Target Regional Hydrology Networks

	Station Number or Stream Name	Drainage Area (km^2)	Selected for Network: M= Minimum T= Target
REGION A			
ZONE 9	01AF007	339	T/M
	01AG002	199	T/M
	Siegas R.	<100	T/M
ZONE 10	01AH005	230	T/M
	01BE001	2270	T/M
	Upsalquitch	500-1000	T/M
	lower Tobique	<100	T/M
ZONE 14	01AD003	1350	T
	01BC001	3160	T/M
	01EJ007	7740	T/M
	Iroquois R.	<200	T/M
	Kedgwick R.	400-1000	T/M
	Gounamitz R.	<200	T
ZONE 15	01BJ012	43.2	T/M
ZONE 16	01AE001	2260	T/M
REGION B			
ZONE 5	01AJ010	350	T
	01AJ011	156	T
	01AL002	1450	T/M
	01AL003	6.48	T/M
	01AL008	641	T
ZONE 6	Cains R.	>500	T/M
	Cains R.	100-500	T/M
	S. Branch Renous	<100	T/M
ZONE 11	01BP001	1340	T/M
	01B0001	5050	T/M
	01B0002	611	T/M
	Tuadook R.	<100	T/M
ZONE 12	01BK006	13.0	T/M
	01BQ001	948	T/M
	Nepisiquit R.	250-500	T/M

continued...

Table 3.1 (continued)

Station Selections for Minimum and Target Regional Hydrology Networks

	Station Number or Stream Name	Drainage Area (km^2)	Selected for Network: M= Minimum T= Target
REGION C			
ZONE 13	01BL001	175	T
	01BL002	173	T/M
	01BL003	383	T/M
	01B0004	316	T
	upper Tracadie	<100	T/M
	Tabusintac R.	<120	T
ZONE 15	01BJ001	363	T
	01BJ003	510	T/M
	01BJ010	190	T/M
	01BJ011	123	T
REGION D			
ZONE 7	01AN001	34.4	T/M
	01AN002	1050	T/M
	01AP002	668	T/M
	lower Canaan	<100	T
ZONE 8	01B0003	484	T/M
	01BR001	177	T
	01BS001	166	T/M
	01BT001	32.1	T/M
	Kouchibouguac R.	<100	T
	Tantramar R.	<100	T
REGION E			
ZONE 1	01AQ001	239	T/M
ZONE 3	01AP004	1100	T/M
	01BU002	391	T/M
	01BU003	129	T/M
	Trout Creek	80	T/M
	Memramcook R.	<150	T
ZONE 4	01BV006	130	T/M
	01BV005 restart	29.5	T/M
	01BV008 restart	287	T/M
	Shepody R.	<80	T

continued...

Table 3.1 (concluded)

Station Selections for Minimum and Target Regional Hydrology Networks

	Station Number or Stream Name	Drainage Area (km^2)	Selected for Network: M= Minimum T= Target
REGION F			
ZONE 1	01AQ008	197	T
	01AR006	115	T/M
	Digdeguash R.	>500	T/M
	01AR008 restart	43.0	T/M
ZONE 2	01AM001	557	T/M
	01AO009	93.2	T
	01AP006	293	T/M
	Corbett Brook	15	T/M
	Nerepis tributary	<100	T
ZONE 5	01AK005	26.9	T
REGION G			
ZONE 5	01AJ003	1210	T/M
	01AJ004	484	T
	01AK001	234	T/M
	01AK007	240	T
	01AK008	531	T/M
	Keswick R.	>500	T
REGION S			
ZONE 14	01AD002	14700	T/M

3.3 A TARGET REGIONAL HYDROLOGY NETWORK

3.3.1 Data Transfer Methodology

Probably the most widespread application of a regional hydrology network is the use of data transfer techniques to provide estimates of the magnitude and frequency of streamflows at ungauged sites. It was seen that the Minimum Network as defined above cannot provide that capability, primarily due to insufficient sample size to satisfy statistical criteria and inadequate representation of the variance in drainage area. The target, therefore, became a network which would support data transfer methodologies for the purpose of estimating hydrologic information at ungauged sites.

A review was undertaken of the various available hydrologic transfer techniques, to determine which would best suit the needs of this study. Two general classes of techniques were available:

a) the use of hydrologic models which define relationships (eg. between rainfall and runoff) and require calibration using the data particular to the study area under investigation, and

b) the use of statistical methods wherein relationships are determined from the data available and subjected to various tests to identify statistical significance (ie. confidence).

It was determined that the present lack of coordination between hydrometric and climate networks in the province made the use of hydrologic models unfeasible, due to insufficient data to represent the spatial and temporal variation in the climatic parameters. Regression analysis was the statistical method most familiar to team members and has the advantage of serving as an indicator of how well the transfer function is performing. In particular, the Generalized Least Squares method (GLS), which was applied here, ranks stations in terms of their individual contribution to the estimating equation.

3.3.2 Determination of Hydrologic Regions

One approach to the determination of hydrologic regions might have been to augment the sample size within each of the physiographic-climatic zones identified for the Minimum Network to a sufficient size to satisfy statistical criteria. This, however, would require a very substantial expansion of the present network (in excess of 100%), and was not regarded as a realistic approach.

Instead, regression analysis was applied to the existing hydrologic record for the province to determine zones of homogeneity with respect to high, mean and low streamflows. The objective was to establish a workable number of representative units within which regional estimation equations could be applied, with statistical confidence, for the transfer of hydrologic information to ungauged sites.

The multiple linear regression analysis for mean flow involved developing regional equations for the 2 year (median), 10 year and 100 year annual mean flows. The usual multiple linear regression method, ordinary least squares (OLS), was employed, as well as generalized least squares (GLS), a technique which takes into consideration the correlations and distances between the stations as well as the varying lengths of record among the stations. Drainage area and mean annual precipitation were found to be the significant parameters in these regression equations which provided standard errors between 10% and 14% with both OLS and GLS on a province-wide basis. The residuals indicated that two regions could exist, and further equations, using the homogeneous regions shown in Figure 3.3 were developed. The resulting standard errors were similar to the province-wide equations. Because of the low standard errors that were obtained, it was concluded that the network presently provides users with estimates of mean annual flows which most, if not all, would find acceptable.

The multiple linear regression analysis for low flow involved developing regional equations for the 2 year, 10 year and 20 year 10-day mean low flow with both OLS and GLS. Significant parameters were found to be drainage area, baseflow index (BFI), mean annual precipitation and percentage of lakes and swamps for the province-wide equations. BFI, which is based on the proportion of runoff contributed from baseflow, is an index of geology. The standard errors varied from 30% to 54%, which was comparable to previous studies elsewhere. Based on the pattern of residuals as well

as physiographic-climatic considerations, four low flow regions were determined for which further equations were developed. The resulting regional equations showed a wide range of standard errors, from 9% to 58%, with various combinations of the four physiographic-climatic parameters mentioned earlier.

Because of the lack of data for small basins, it was decided to assess their influence in estimating low flows by dividing the network into two equal groups containing the largest size and the smallest size stations. The regression equations on these two groups pointed out that smaller basins account for greater low flow variability, and that drainage area explains less of this variability in small basins than in large basins. Furthermore, it was found that geology, as represented by BFI, explains more of this variability in small basins than for larger basins. It was concluded that there was a need for more small basins in the network in order to extend the parameter range of the developed equation.

The multiple linear regression analysis for flood flows involved developing regional equations for the 2 year, 20 year and 100 year floods with GLS. A previous study (Inland Waters/Lands Directorate, Environment Canada and New Brunswick Department of Municipal Affairs and Environment, 1987) had performed the OLS analysis and had determined four homogeneous flood regions in addition to the Saint John River main stem. The standard errors on both a province-wide basis and for the homogeneous regions were of an order similar to that of other regional flood studies, generally around 20%.

As in the case of low flows, it was again concluded that the present network is deficient in small basins throughout New Brunswick.

The capability of the regional hydrology information base to provide estimates of daily mean flows was also assessed during this process, using flow duration analysis. Because local factors like ground water storage, location of tributaries and location of lakes and swamps are likely significant variables in defining flow duration curve shape, it was impossible to develop regional flow duration curve equations with sufficiently low errors with the available physiographic-climatic data bases. It was concluded that for locations where daily mean flows are required by users on a regular basis, only hydrometric stations (as opposed to estimations) can currently fill that need.

3.3.3 Target Criteria and Station Selection

To complete the determination of hydrologic regions, the homogeneous areas identified through the development of high, mean and low flow equations were overlayed and fit into the seven hydrologic regions shown in Figure 3.4.

In order to provide a credible capability for the transfer of hydrologic information to ungauged sites within any particular region, it was felt that a minimum of two significant parameters was essential for each regional equation. Applying the criteria of a minimum of 5 hydrometric stations (4 degrees of freedom) for each parameter to satisfy the requirements for statistical significance, a minimum of 10 gauging sites was accordingly identified for each hydrologic region.

Using the previously determined Minimum Regional Hydrology Network as a building block, additional gauging sites were added, using the criteria identified above, to arrive at the resulting Target Regional Hydrology Network. Because hydrologic regions A and B of Figure 3.4 are so large, it was decided to include 15 stations in each of those regions. Six stations were considered sufficient for region G since it is so small and because it is partly in Maine where additional stations would be available. Regions C,D,E and F each contain 10 stations. Table 3.1 presents a listing of the gauging sites selected for both the Minimum and Target Regional Hydrology Network. Those which already exist within the present network are identified by their Water Survey of Canada code. Proposed new stations are identified by their stream name. The corresponding drainage area for each site is also provided.

Figure 3-4 Homogeneous Hydrologic Regions of New Brunswick

3.4 SUMMARY

Two sets of criteria were developed for assessing the spatial representation of regional hydrology in New Brunswick. The Minimum Regional Hydrology Network was based on areas of physiographic-climatic similarity. As such, it represents a 'lower bound' or the most rudimentary coverage. It does not provide capability for transfer of hydrologic information to ungauged sites. Rather, it provides no more than a capability to make some untested generalizations with respect to the hydrology within each of the 16 identified physiographic-climatic zones. The more comprehensive criteria developed for the Target Regional Hydrology Network were constructed utilizing statistical methodologies (regression analysis). The resulting network does provide the capability for data transfer within each of the 7 identified hydrologic regions.

Seventeen (17) new station sites must be substituted to provide the prescribed minimum coverage. Twenty-six (26) new sites are required to provide the prescribed target coverage.

The present network is considered adequate to fulfill user needs for mean annual flow. The standard errors for the low flow and flood frequency equations, while comparable to other studies, are unsatisfactory; they do not meet user needs.

Because of the restrictive drainage area range of all developed regional equations, additional hydrometric stations to monitor flows from small basins should be established so that the equations can be applicable under a greater number of circumstances.

Station coverage is incomplete in the central portion of the province. Additional hydrometric stations should be established there.

Both the Minimum and Target Regional Hydrology Networks were compared with the present network to determine deficient and/or redundant aspects of the present coverage. The resulting information was input to the Station Audit exercise described in Chapter Five to determine overall station priorities.

4.0 TECHNOLOGICAL AND OPERATIONAL ISSUES

4.1 GENERAL

Acquiring an adequate data bank of hydrometric information depends upon the use of cost-effective and reliable instrumentation and operational procedures at the carefully selected gauging sites.

In a previous hydrometric network review, a general recommendation was made for the increased use of equipment in support of automatic data storage and processing procedures. This was recognized as more important to short-term project and operational needs than long-term data collection. However, it was also recommended to implement new equipment and procedures into the long-term data collection network with the objectives of making data available on a near real-time basis and reducing operational costs (Environment Canada and the Department of Municipal Affairs and Environment, 1979).

Consideration of selected technological and operational issues was a component of this hydrometric network evaluation. The problem was to determine what instrumentation should be used and what operational procedures should be followed to reliably obtain accurate data.

Consideration of technology and operations is an important component of hydrometric network evaluation for the following reasons:

(1) new technological and operational options allow the development of hydrometric networks that can provide more comprehensive and varied information more effectively than has been possible before;

(2) technology and operational procedures directly impact upon the costs of constructing, operating and maintaining a hydrometric network, and hence determine the extent of the net benefits to be obtained;

(3) user expectations as to the type, accuracy, reliability, and immediacy of hydrometric data have been evolving due to changing needs for data and more widespread use of computerized data handling packages and hydrologic software and;

(4) the operating environment of data collection agencies has been altered due to social and political pressures for public agencies to reduce expenditures while maintaining or improving their level of service.

It was impossible to discuss in Background Report No.4 all the technical and operational concerns that can exist in designing, maintaining and operating hydrometric networks. Therefore, it was necessary to limit the coverage of the report to a few topics deemed by the authors of importance and relevance to the present network evaluation. Selected topics which are primarily technological in nature were stage measurement technology, velocity and flow measurement technology, and telemetry, as well as the difficult problems of flow measurement during ice cover periods, flow measurement during breakup and estuarial flow measurement. Selected topics which are primarily operational, such as, observers and remote sensing, term stations, frequency of visitation, and transboundary interjurisdictional concerns were addressed. The background report also contains a visionary look at future hydrometric networks.

4.2 EMERGING TRENDS

The technology used in the New Brunswick hydrometric network is changing due to user demands for greater accuracy, reliability and timeliness of data as well as pressures on public agencies to reduce expenditures while maintaining or improving level of service.

The installation of micro-processor based data acquisition systems began in 1982 with the introduction of the data collection platform. Presently, there are 10 Data Collection Platforms (DCPs) operational in the New Brunswick hydrometric network. They have already had a positive impact on the operation of the network by reducing record loss in two ways:

(1) hourly records from DCPs have been used to produce stage hydrographs during periods when the analogue recorder at a station has malfunctioned; and

(2) equipment malfunctions have been identified by DCP and technical staff are sent to the station to correct the problem.

In addition to reducing record loss, DCPs have led to more efficient use of personnel. Using real-time data from DCPs, the field trip plans can be made such that flow measurements are made during optimum stream conditions.

In view of the positive results achieved to date, a program to totally automate hydrometric data acquisition has been proposed. Effective automation in terms of a hydrometric network operation requires that data acquisition both at the unattended hydrometric station and through activities conducted by field parties be viewed as components of a complete system.

A description of potential instrumentation pertaining to an automated hydrometric data acquisition and telemetry system is provided below.

1. Electronic Data Acquisition Systems (EDAS):

This can be considered the heart of an automated data collection program and the main development focus has been to produce an instrument through which the basic parameters defining a hydrological event can be monitored. These parameters are stage, slope and velocity. To maximize benefits, data on these parameters must be acquired automatically and transmitted to the hydrometric station network operator in a time frame consistent with the hydrological event response characteristics.

In addition to hydrometric network operating requirements, pressures exerted by clients, the economy and politics demand that additional sensor interfacing capability be incorporated in the design criteria of the system. This has been taken into account. Figure 4.1 is an illustration of the design concept of the EDAS.

2. Hydrometric Sensors:

To make automation of hydrometric data collection feasible, the data collected at a station must provide sufficient information to permit the analytical reproduction of a hydrological event. The minimum parameters to be sensed under this criteria are stage, velocity and slope. Sensor development for each parameter is discussed below.

1. Stage

The stage sensing instrumentation development strategy is to improve flexibility and decrease complexity and cost of current stage sensing equipment. Two operating principles are under consideration, i.e. pressure-sensing instruments and distance measuring devices using ultrasonics. Design characteristics of both sensors will be such that they meet WRB accuracy and reliability standards and that they are electronically compatible with the data acquisition system EDAS.

Figure 4-1 Water Resources Branch, Environment Canada, Electronic Data Acquisition System Configuration

2. Velocity:

WRB has investigated the potential of ultrasonic and electromagnetic flow measuring principles and instrumentation for application to its hydrometric network operation. Of the two, the ultrasonic flow meter is considered as producing the most cost-effective results. The decision was made to develop an ultrasonic flow meter which would operate under Canada's varied climate and have the capability to transfer data to an Electronic Data Acquisition System for transmission. The flow meter is expected to provide near continuous data on flow velocity which when combined with stage and water surface slope will define a flow event.

3. Slope:

This is the last of the three parameters required to define a hydrologic event at a station. This development will be an extension of the pressure transducer development project.

In parallel to the instrumentation development described above, an investigation is being carried out on portable computers developed specifically for use in the field under Canada's harsh climatic conditions. Devices of this sort will ensure that all data received from the field either from unattended sites or through field staff activity will be compatible with electronic data handling and processing activity. The field computer will have the ability to communicate directly with any micro-processor controlled field instrument or office computer.

To ensure the timeliness of hydrometric date acquired for near real time use e.g. flood forecasting, reservoir operation, navigation etc., Environment Canada is installing three satellite data ground stations for the reception of data transmitted via the Geostationary Operational Environment Satellites (GOES). The facilities are expected to commence operation during the fall of 1988.

4.3 SUMMARY

The use of cost-effective and reliable instrumentation and operational procedures at all stations in the network is a logical next-step subsequent to network planning.

The increased use of equipment in support of automatic data storage and processing procedures is recognized as more important to short-term project and operational needs than long-term data collection. However, the implementation of new equipment and procedures into the long-term data collection network with the objectives of making data available on a near real-time basis and reducing operational costs is just as important.

The consideration of selected technological and operational issues was to determine what instrumentation should be used and what operational procedures should be followed to reliably obtain accurate data.

The technology used in the New Brunswick hydrometric network is changing due to user demands for greater accuracy, reliability and timeliness of data as well as pressures on public agencies to reduce expenditures while maintaining or improving level of service. The installation of micro-processor based data acquisition systems began in 1982 with the introduction of the data collection platform. Presently, there are 10 Data Collection Platforms (DCPs) operational in the New Brunswick hydrometric network. They have already had a positive impact on the operation of the network. In view of the positive results achieved to date, a program to totally automate hydrometric data acquisition has been proposed.

5.0 EVALUATION OF GAUGING STRATEGIES

5.1 GENERAL

5.1.1 A Framework For Evaluation

As Moss (1979) observed, "current usage of the term 'data network' frequently refers to an amalgam of data collection activities (usually a specific set of measuring sites) all of which contribute to a somewhat vague goal".

The first step at proper planning and evaluation will then be to provide a more defined goal; to get away from the "amalgam of activities" image; and to identify achievable, measurable dimensions for the network which can be subjected to analysis to determine performance.

The worth of the network is defined in terms of the information's utility to users. The first requirement of the evaluation is, therefore, an accurate definition of the users' perceived needs (current and future). Subsequently, the capability of the network to address these needs must be assessed. This process will identify deficiencies in the network, as well as redundant information, thereby providing an implicit strategy for network planning.

Consideration of the budget or cost constraint will require that the network be regarded in a supply/demand context in order to determine priorities for network outputs based on some measure of relative worth. It is realized in the course of this effort (due to the random nature of the relevant variables, the sensitivity of results to varying assumptions, and the difficulty of apportioning benefits to individual users) that the methodology for determination of relative worth will have to be more pragmatic than rigorous.

5.1.2 What Are The Assumptions?

In undertaking the determination of priority outputs, five important characterizations are drawn of the hydrometric network. The first is that it really **comprises two networks:** (a) an "Operational Network" wherein data needs are typically site-and-purpose-specific, often real-time, and the data are required for direct input to operational activities - e.g. reservoir regulation; and (b) a "Regional Hydrology Network", wherein regional generalizations of data are typically sufficient, future needs must often be anticipated, and the data are applicable and available to a number of purposes and users, normally of a planning, design or investigative nature.

The second characterization is that, with limited resources and for a given level of accuracy, the network is a **composite of space-time trade-offs.** Resources allocated to continuing the period of record at one site will be at the expense of establishing a record at an alternate site and vice versa.

The third important characterization is that the hydrometric information base is not simply a collection of gauging station records. It is a **combination of gauging records and hydrologic estimations** which together provide the required information.

Implicit in these three characterizations is the obvious recognition that some sites will be more important than others. The evaluation methodology presented here is an attempt to incorporate these aspects into a framework which permits comparisons among (both existing and proposed) sites so as to arrive at an ordering of relative worth among them. **The most cost-effective network configuration will then ideally comprise the highest valued station and as many others of descending priority as permitted within a particular budget constraint.**

The fourth assumption is that the design of the network is the primary focus of the present exercise. Although efficiency of operations is also an important aspect of network evaluation, it is conceptually a very different 'animal'. It is very dependent on the technology being employed (which at present is in a somewhat transitional phase), and it is, to a large extent, an exercise in 'activity planning', thereby typically impacting on network performance in a complementary rather than a functional manner. Chapter Four has already addressed a number of technology and

operational considerations important to the New Brunswick network. Those elements which can be identified as impacting on the relative efficiency of the network will be included in this evaluation exercise.

The fifth assumption is that this evaluation exercise is not an attempt to determine a benefit/cost value for the New Brunswick hydrometric data program. The literature commonly acknowledges that the value of benefits from hydrologic networks is high relative to costs. However, as is discussed further in section 5.3.1 of this chapter, attempts to determine specific values are simply too assumption-sensitive for practical application.

Rather, it is being assumed here, as is reflected in the commonly regarded mandates of the federal/provincial water data programs, that:

- there is a public good responsibility incumbent on governments to provide "some" level of hydrometric information;

- it will be more productive for needs beyond "that" level to be treated as increments to a core network rather than for and all sundry to establish a plethora of mini-networks of varying quality and consistency; and

- there will be public resources allocated for the provision of this public good.

Accordingly, this exercise will be directed at prescribing the most effective use of the public resources allocated to the provision of hydrometric information in New Brunswick.

5.2 A SUPPLY/DEMAND CONTEXT

5.2.1 Demand (User Needs)

Chapter Two has provided an overview analysis of the results of the user surveys, generally identifying the "market" for hydrometric information, and the characteristics, patterns and trends particular to the New Brunswick user community.

In an evaluation context, these characteristics are most important in identifying the purposes to which the information required is being applied. As has been indicated earlier, these purposes may be categorized as either Operational or Regional. The identification of Operational needs is quite straightforward. The requirements are specific to a particular site and purpose, which typically entails the use of real-time data for monitoring or operation of a facility.

Regional hydrology needs, on the other hand, are less readily categorized. The essential purposes to which they apply have been described in numerous and varied manners in the literature:

McLaurin et al (1986) identify four categories of regional hydrology needs: (i) a continuing inventory of water supplies in major rivers and lakes for basic knowledge and public interest; (ii) a network of long-term high accuracy stations to monitor and assess hydrologic changes in major physiographic zones; (iii) instrumented research basins that aim for improved understanding of hydrologic processes; and (iv) a network able to estimate specified flow characteristics in ungauged areas to specified accuracy requirements.

Wahl and Crippen (1984) provide a somewhat similar breakdown: (i) current uses; (ii) planning and design; (iii) definition of long-term trends; and (iv) defining the stream environment.

Thomas and Benson (1975) cite the purposes of the natural flow stream gauging system of the USGS as: (i) assessing the availability of the Nation's natural resources; (ii) planning and design of hydraulic structures; (iii) planning land use; and (iv) answering unanticipated questions on streamflow.

Moss (1979) provides an overview perception that: servicing unanticipated demands is the primary role that national networks fulfill.

Langbein's identified requirements (1979) are more closely related to the "public good" notion of the

network referred to earlier in this chapter: (i) long-term trends - to look ahead and detect deterioration; (ii) cause/effect - to detect and understand future consequences of present day choices and evaluate success of management choices; and (iii) high quality data - to assure a publicly credible basis for controversial decisions.

The variations in the above perceptions of the demand for hydrometric information are perhaps more semantic than substantive. Their summation is well-expressed by the WMO (1981): to obtain an appreciation of the availability of surface waters, their geographic distribution, and their variability in time.

5.2.2 Supply (Data and Information)

In the same sense that demands for Operational data are site-and-purpose-specific, the supply or provision of this information simply entails the establishment of real-time measurement capabilities at the required sites.

The supply of Regional Hydrology data, on the other hand, is not so simple a task. As Shen (1972) appropriately notes:

"Hydrologic data are random variables. The information given by the hydrologic data is used for decision purposes (which determines its worth); thus the worth of data is also a random variable."

The key implication is that, with varied and ever-changing needs, **the provision of regional hydrology information must typically anticipate or project an uncertain demand**, both in terms of required location and planning period. Network output or supply in this context is then measured by its ability to reduce uncertainty. This capacity is referred to as the reliability of the network.

Measurement error aside, reliability of the network comprises:

- accurate estimates of the relationships between hydrologic variables and basins characteristics;

- accurate representations of sampled data for hydrologic relationships at ungauged sites; and

- sufficient period of record. (Attanasi and Karlinger, 1977)

5.2.3 Optimality and Unicorns

Artists have painted it, folklorists have sung of it and fairy tales have told of it - the fabled unicorn. Yet none have any evidence of its existence.

Similarly, economists envisage perfect markets with equilibrium of supply and demand curves or marginal benefit and marginal cost, and statisticians conceive of zero-error regression models - as representations of the fabled optimal network. Yet neither have evidence of its existence. The elusive nature of this unicorn is highlighted by Moss' (1979) observation that,

"It is a paradox of network design that the statistical parameters controlling the optimality of a network are frequently the unknowns that the network is being designed to estimate..... The dispersion of the sampling distribution, and thus the inaccuracy of an estimate of the variance, is a function of the variance itself".

It is apparent that the notion of optimality, as it relates to network design, is fuzzy at best. Its realistic definition, and therefore its achievement, can only be approximated.

In the regional hydrology (i.e. natural flow) context, an approximate demand-side perception of optimality is that there be no deficiencies in the information base. That is, the hydrology is sufficiently gauged that high, mean and low flow relationships are available for any small, medium and large basins in the Province. This sufficiency would be characterized by water management decisions being insensitive to any additional hydrometric data.

Similarly, an approximate supply-side perception of optimality is that there be no redundancies in the network. That is, only the minimum necessary combination of gauging density and period of record is being operated to provide reliable estimates of these relationships. In this context, the hydrologic relationships would be sufficiently understood that any variability in estimates would be due to variability in climatic inputs and physiographic conditions.

When the Operational and Regional Hydrology networks are superimposed, a further dimension of optimality is identified - maximum utilization of common facilities for mutual needs. That is, information provided for operational needs is utilized to serve regional hydrology needs whenever possible, and vice versa.

The final dimension of optimality identified here is regarding the cost or budget constraint. Except in unusal circumstances, the level of available resources will typically be less than what is perceived as necessary to provide the so-called optimal network. The imposition of a budget therefore gives rise to the concept of a constrained optimum - the best possible, given available resource; i.e. the most cost-effective network.

The next two sections examine the criteria appropriate to defining such a network, review the cost-benefit methodologies discussed in the literature, and propose a pragmatic approach to capturing the unicorn (i.e. approximating the optimal network) within the framework of cost-effectiveness criteria. Section 5.5 then discusses the implications of this evaluation in terms of alternate gauging strategies for the network.

Each gauging strategy will imply a particular level of reliability as represented by some combination of period of record and gauging density and will be constrained by a particular assumption regarding available resources. The so-called optimal network will of course have the most "relaxed" budget constraint. Imposition of tighter constraints will imply movement along a cost-benefit curve. An attempt will be made to identify relative positions on this curve associated with the varying budget assumptions.

5.3 COST-BENEFIT CONSIDERATIONS

5.3.1 Benefits

Following on the theme that the value of hydrometric information is derived from its use, the following Table 5.1 has been constructed, identifying the various activities/uses for which hydrologic information is required, and the particular network output(s) important to each use.

This table is not intended to be an exhaustive listing, nor the identified relationships conclusive. Rather, its purpose is to illustrate the breadth and multi-facetedness of the benefits of hydrologic information. **It is these dimensions which present the most significant stumbling blocks to the valuation of benefits.** In fact, one of the main findings of a workshop held by the World Meteorological Organization (WMO) on Cost-Benefit Assessment of Hydrologic Data (1982) was that, due to lack of information on benefits derived from hydrologic data, the majority of contributions to the literature presented at the workshop were regarded as mainly theoretical, requiring complex computations for simulation of large numbers of synthetic time-series. Those which avoided the need for simulation were of practical value only for certain types of very simple situations.

The inability to specify benefits has led the bulk of the literature to focus on variance analysis of change in error as a surrogate approach. Typically, due to the complexities involved, these approaches have had to limit themselves to individual-project-with/without situations. In this way, rather than attempting to derive a benefit value per se, the assessment needed only focus on statistical determinations of relative gain or loss of information (as represented by reduced or increased hypothesized error) for each situation.

The references at the end of this report document many of these error-analysis approaches, as well as other approaches based on such theoretical notions as equivalency of marginal cost and benefit, social welfare optimization, and decision theory utilizing complex Bayesian statistics and Monte Carlo simulations. While these theoretical approaches probably hold merit in the ranks of mathematical rigour, their usefulness for practical applications is quite limited, for some very significant reasons:
First, referring to Table 5.1, it is evident that the various network outputs (yields, extremes, distribution and accuracy) are of varying value to each use and to each user. It is difficult enough to pose a specific benefit value for hydrologic information for a single use. **When the same information is available to, and is shared by many users in varying degrees (i.e. with different response functions), and with significantly varying economic consequences (i.e. different loss functions), the <u>apportionment</u> of benefits to each of these uses becomes either impossible or arbitrary.** Consequently, the aggregation of the value of benefits derived from all uses becomes speculative at best.

Secondly, as discussed earlier in this Chapter, one of the most important applications of regional hydrology information is in servicing future and unanticipated demands. It follows that, if the set of demands is never finite, the total benefits derived from these demands can never be fully known, thereby leaving the valuation of benefits incomplete at best.

Thirdly, the with/without approach to error analysis presumes that a project may be postponed or deferred without the required hydrologic information. While this may be true for an "infant" network-individual project situation, it is far removed from our present situation of a "reasonably mature" network serving multiple needs.

And finally, error analysis by itself is incomplete in that it prescribes performance only on the basis of statistical criteria (i.e. tests of significance), without assigning a level of value or benefit to the satisfaction of these criteria.

In view of such conceptual hurdles in the valuation of the benefits of hydrologic information, Langbein (1979) quotes Rodriguez-Iturbe's conclusion that, "because of complex objectives, structured analysis can be applied only to special or single-purpose (say captive) networks and rarely to national or even regional networks". He observed (with regard to the latter) that "**optimization may make no more sense than common sense**". Dawdy (1979) takes this thought further in suggesting that, "**Simplicity is required if there is to be any impact on decision makers.** That simplicity may come from elegance, but it is more likely to come from brute force approximations. Both have their place if they help solve the problem. Neither is of much use if the results do not, eventually, end up influencing decisions".

TABLE 5.1

USES OF HYDROLOGIC INFORMATION

Activity/Use	Primary Network Output Required		
	Average Quantities ie Monthly Yields	Temporal Variability (Extremes ie flood and drought)	Spatial Distribution (ie wet and dry areas)
Conservation & Protection			
- resource availability (inventories)	X		X
- hydrologic change (long term)	X	X	X
- environmental management	X	X	X
Planning, Design and Research:			
- regional hydrology knowledge base	X	X	X
- damage avoidance (extremes)		X	
- land use planning		X	X
- environmental impact	X	X	X
- hydraulic design	X	X	X
- improved understanding	X	X	X
- withdrawal/instream use	X	X	X
Monitoring and Operations:			
- utilities	X	X	X
- forecasting (extremes)		X	X
- apportionment, levels, objectives	X	X	X

Despite the inability to quantify benefits, however, it is generally acknowledged in the literature that the benefits of regional hydrology networks are high relative to their costs. This perception is largely derived from the "public good" values associated with centralized networks. That is, assuming that governments require at least a core network to meet mandated and stewardship responsibilities for water management, then there will be economies of centralization and enhanced reliability derived from "adding-on" to this core network, rather than establishing separate individual networks of varying quality and consistency to address each new need as it arises. Further, as discussed in the next section, there are substantial savings in the cost of data-dependent public works realized through the establishment of the core network itself.

5.3.2 Costs

Assessment of the costs of a hydrometric network is, conceptually, a much easier task than assessment of the benefits, and is typically a function of the technology employed and the scale of operations. Although there are still problems of apportionment similar to those associated with valuation of benefits, these problems are more readily resolved in the case of costs.

Table 5.2 itemizes the operational costs for the New Brunswick Hydrometric Survey for 1986-87.

It can be seen from the table that the elements which comprise the total cost of operations of a network do not readily lend themselves to the construction of a smooth, continuous, divisible marginal cost function for analytical purposes. It is much more realistic to regard cost as functionally related to "blocks" of stations rather than individual increments. It would be difficult, for example, to identify a station's-worth of salary or data processing costs. A more practicable definition would relate the number of stations which could be addressed by a PY or by X-dollars of processing costs. For this reason, it is felt that the use of an average or unit value as the representative cost variable will be the most appropriate approach.

The estimated average cost per station for the New Brunswick network in 1986-87, based on 83 stations, was $3,618. Table 5.3 shows how this figure compares on a historical basis over the period of federal-provincial cost-sharing.

These operational costs may be related to the alternative costs of undertaking hydrologic

data-dependent activities in the absence of an established network. It has been estimated, for example (see Table 5.4) that for only a small single-purpose hydrologic project (eg. a secondary highway bridge), there is approximately a 75% difference in cost between computing a design flow with and without access to established data at or near the site.

As Table 5.4 notes, not only would this cost difference become more excessive for larger and more complex projects, but also the established record is available for any number of projects, while the synthesized value is typically not applicable on a regional basis. Additionally, the established record is generally more accurate than a modelled flow.

Approximately $40 million is expended annually by the Province of New Brunswick alone on public transportation and water works infrasturcture requiring hydrologic design data. The cost implications of undertaking these efforts in the absence of established data, are apparent, particularly when one adds in federal and municipal public works, as well as the whole array of other uses identified by the user surveys.

TABLE 5.2

OPERATIONAL COSTS FOR NEW BRUNSWICK HYDROMETRIC SURVEY 1986-87

Salaries	$208,674
Transportation and Communication:	
- Travel and Removal	18,199
- Transportation and Postage	613
- Telecommunications	432
Professional and Special Services	2,984
Rentals	861
Purchased Repair and Upkeep:	
- Purchased Equipment and Repairs	3,165
- Building and Structure Repairs	---
Utilities, Materials and Supplies:	
- Public Utility Services	3,318
- Purchased Materials	15,018
- Parts and Consumable Tools	9,880
Other Costs:	
- Data Processing	10,397
- Depreciation of Vehicles	11,178
- Depreciation of Field Equipment	15,611
TOTAL	$300,330

TABLE 5.3

NEW BRUNSWICK HYDROMETRIC NETWORK

Year	No. Stations	Average Cost per Station
1975-76	79	$2,422
1976-77	85	2,458
1977-78	85	2,634
1978-79	84	2,582
1979-80	79	2,781
1980-81	77	2,727
1981-82	78	3,192
1982-83	83	3,192
1983-84	84	3,508
1984-85	82	3,689
1985-86	83	3,635
1986-87	83	3,618
1987-88	83	3,618 (Preliminary)

TABLE 5.4

EXAMPLE OF USER SAVINGS DERIVED FROM A REGIONAL NETWORK

Project: A small highway bridge. The hydrology requirement is a design flow for a bridge over a river with a 250 km^2 watershed.

A. Cost with Existing Hydrologic Record at or near Site:

- Field visit	1 - 2 days
- Perform frequency analysis and evaluate	1 day
- Select design flow and report	1 day
	3 - 4 days @ $450/day = $1,350 - $1,800

B. Cost without Existing Hydrologic Record at or near Site:

- Field Visit	1 - 2 days
- Information gathering (maps, plans, rainfall, land use, etc.)	2 - 3 days
- Select, set-up and calibrate model	3 - 5 days
- Perform and evaluate model computations	2 - 3 days
- Select design flow and report	1 -2 days
	9 - 15 days @ 450/day = $4,050 - $6,750

Notes:

1. The public saving, in design costs only, for this project alone may be as much as 70%. Provincial expenditures alone, for such hydrometric data dependent works exceed 40 million dollars annually. Federal and Provincial expenditures are additional. These are supported by a network operating cost of 0.3 million dollars annually. Additionally, the same existing record will be available for any number of projects.
2. The estimated savings are for a small single-purpose project. These would be substantially magnified for any multi-purpose projects involving larger areas and multiple design points.
3. Accuracy of the "modelled" flow will be less than that for the established record.
4. The modelled flow will not typically be applicable for regional hydrology information, while the established record would be and the established record will be available for any number of projects.

5.4 A PRAGMATIC APPROACH

5.4.1 The Station Audit Concept

The preceeding sections of this Chapter have identified the problems of attempting a rigorous approach to the determination of the costs and benefits of hydrometric information. These problems have highlighted the need for a more pragmatic approach to the task of evaluating hydrometric networks; one which focuses more on relative than absolute determinations of cost and benefit, and one which readily lends itself to implementation.

Referring back to Langbein's paradox cited at the beginning of this Chapter, he goes on to suggest that an audit type of evaluation approach would provide a practical means of assessing the potential mis-match between the network and identified needs resulting from objectives changing over time; i.e. current objectives (needs) differing from future ones and historical needs differing from current needs.

By addressing the network so as to provide for orderly replacement of stations which have completed their function, with stations which address newly defined needs, both redundancies and gaps in the network will be minimized, thereby providing an approximate equilibrium of Supply and Demand over time, and hence maximization of cost-effectiveness.

In the same sense that a financial audit utilizes a balance sheet, we are accordingly utilizing a **station audit approach which assesses the balance between the information network and the identified needs (i.e. supply and demand) over time.**

Under this approach, the greater the extent to which a particular station contributes to identified needs, the greater the value of benefits derived. Accordingly, the "auditing" of each station in the network (including any proposed new stations) entails the assessment of their relative contributions to needs (i.e. relative to each other). This enables us to focus on comparisons of relative increase or decrease in benefits, rather than get bogged down in the issue of the level of benefits per se and their apportionment.

5.4.2 Audit Criteria

The evaluation framework developed to undertake the station audit process was adapted from a method presented by K. Wahl and J. Crippen of the USGS (Wahl

and Crippen, 1984).

In the Wahl-Crippen approach, a framework is developed for rating each station according to selected priority considerations. These considerations related to the need for information at the site, accuracy of data, economic aspects of operation and usefulness of data as a basis for estimates at ungauged sites. The intent was that points be assigned to each station on the basis of how they rated against each consideration, and the "best" stations would be the ones with the greatest accumulation of points.

Since Wahl and Crippen only presented the analytical framework, without attempting to apply it, and since many aspects of our exercise differed from the Wahl-Crippen setting, it was found that certain dimensions needed to be expanded on, some dropped and others substantially modified in order to custom-fit the evaluation framework to the present exercise.

Table 5.5 identifies the priority considerations against which the New Brunswick stations were rated and the rationale for each rating structure. The choice of priority considerations is outlined briefly below. They were divided into three main groupings: i) site characteristics, ii) client needs and iii) regional importance of the water resource:

5.4.2.1 Site Characteristics:

Included mean annual flow as a proxy for size; differentiated discharge stations from those which only monitor water level; rated the quality of record which was typically a function of how stable the control has proven over the years; identified the period of record to date; and indicated whether or not climate information useful for hydrology purposes was located nearby. **This set of considerations attempts to assess the value of the station site per se.**

TABLE 5.5

NEW BRUNSWICK NETWORK EVALUATION
STATION AUDIT

PRIORITY CONSIDERATION	MAX. AVAILABLE POINTS	RATIONALE
A) SITE CHARACTERISTICS		
1) Mean annual flow (cms)	6	- larger drainages provide a more representative sample for the Province as a whole.
- less than 25	2	
- 25 to 125	4	
- greater than 125	6	
2) Water level only	3	- these stations provide less information than a flow station.
- water level station	3	
- other	0	
3) Quality of record	15	- the better the quality of record the greater the information value.
4) Period of record (years)	10	- short records need to be extended in order to establish a record. Once the record is established it is of decreasing value, with the exception of very long records which become valuable for index purposes.
- 0 to 5	10	
- 6 to 10	7	
- 11 to 15	5	
- 16 to 25	3	
- 26 to 40	7	
- greater than 40	10	
5) Proximity to climate station	5	- stations whose record may be readily related to comparative met data have added information value.

B) IDENTIFIED CLIENT NEEDS

I. Regional Hydrology

6)	Identified for minimum natural flow network.	9/10 - only stations identified as essential for regional hydrology were assigned these points.
7)	Regional hydrology priority code (importance for estimation)	9 - stations which would contribute to enhanced data transfer capabilities were scored here.
8)	Importance for long term index monitoring/ inventories.	8 - priority stations serving the national index network, as well as some others of importance for trans-boundary areas.
9)	Importance for "special" regional hydrology needs (e.g. small basin data, tech. pilot projects, etc.)	10 - also includes special studies and jurisdictional responsibilities.
10)	Client priority	10 - based on user surveys and station audit. Weightings were determined by a consensus of team members.

a) water supply	10
b) "other" infrastructure, transp., sewerage, etc.	8
c) flooding	6
d) environmental impacts (including health)	7
e) fisheries	6
f) energy	8
g) navigation and recreation	5

11)	Also serves identified operational need	6/0 - extra points assigned for stations which served both regional and operational needs.

II Operational (regulated/site specific)

12)	Importance for federal obligations/responsibilities (treaties, agreements, boards, etc.)	10	- only stations serving formal (federal commitments were included here.
13)	Importance for provincial/ responsibilities (agreements, boards, etc.)	10	- only stations serving formal provincial commitments were included here.
14)	Client Priority	10	- based on user surveys and station audit. Weightings were determined by a consensus of team members.
	a) water supply 8		
	b) "other" infrastructure 5		
	c) flooding 9		
	d) environmental impact (incl. health) 8		
	e) fisheries 7		
	f) energy 8		
	g) navigation and recreation 5		
15)	Also serves regional hydrology need	6/0	- extra points assigned to stations which served both regional and operational needs.

C) REGIONAL IMPORTANCE OF WATER RESOURCE

I. Value of Water Resources in Basin

16)	Population density	5	- a prorated general indicator of intensity of water use.
17)	Municipal water use	9	- a prorated indicator from MUNDAT inventory of surface supplies; adjusted for sources outside basin.
18)	Industrial water use	9	- prorated from Industrial Water Use Survey Inventory of surface supplies.

19)	Fisheries priority	8	- generalized CLI sport fishing capability
20)	Hydro potential	8	- based on DOE inventory of major potential sites and Acres study of potential small scale sites.
	- major	8	
	- small scale	4	
	- none identified	0	
21)	Economic Pressure	7	- based on capital works identified in RSCC Register and Information Inventory of capital works.

II. Magnitude of Water Resources Problem in Basin

22)	Flooding	8	- priority sites identified by federal and provincial DOEs.
23)	Water quality problems/ issues	9	- ambient values provided by WQB, point sources identified by EP.
24)	Water shortage potential	10	- Water Use Analysis Model using high growth projections and hypothesized low flows.

5.4.2.2 Client Needs:

Were divided into Regional Hydrology and Operational Needs. Within the Regional Hydrology context, points were assigned if a station was identified for the minimum natural flow network as part of the physiographic-climatic zones exercise; further points were assigned if it was identified for the target or optimal natural flow network (which utilizes statistical or mathematical estimation techniques for data transfer); importance for specially identified regional hydrology needs such as small basins, water quality or sediment studies, jurisdictional responsibilities, etc.; importance for long-term monitoring of national and regional trends in the hydrology; breadth and importance of client applications of the data; and whether operational needs were also served.

Within the Operational Needs context, points were assigned if a station was identified as serving formal federal or provincial commitments (i.e. under an agreement); for breadth and importance of client applications of the data; and whether regional hydrology needs were also served.

These sets of considerations attempted to assess the value of the station as a function of its currently identified uses.

5.4.2.3 Regional Importance of the Water Resource:

Was divided into two groups: indicators of the value of water in use in the basin and indicators of pressures on the water resource base. **This set of priority considerations attempted to determine the anticipated relative importance of station locations for water resource planning and management in the near future.**

Both existing and proposed new stations were rated against the same factors and ranked together. Proposed stations comprised either those suggested by the Data Transfer Working Group for regional hydrology purposes, or those necessary to address specifically identified needs not currently being served.

The greater the extent to which: ideal site characteristics are satisfied, client needs are met, and indicators identify a priority for water management, then the greater the total of Station Audit points accumulated by a particular station. Hence the greater is the perceived worth of the station and the higher the relative value of benefits. No attempt is made to determine a dollar value for the benefits; only an ordering of relative worth. For a given budget, and given a constant average cost (as discussed in the previous section) then the higher the total Station Audit points (i.e. value of benefits) represented by a particular network scenario, the greater the extent to which cost-effectiveness is maximized.

The proposed Station Audit Framework essentially serves as an integrating tool, bringing together under one umbrella, all the relevant considerations for network evaluation: suitability of the station site, representation of the regional hydrology, usefulness for estimation purposes, servicing of client needs and attention to water planning priorities. The framework is admittedly a subjective one. However, the professional attitudes of all team members, the structuring of the framework so as to provide objective guidelines for the assessment process, the comprehensive approach to consistently assessing each and every station against all priority considerations, and the consensus-building approach to the determination of station scores, all combined to make subjectivity a tool rather than a detriment. The following sections briefly describe the scoring process and present the results of the evaluation exercise.

5.5 AUDIT PROCESS

To complete the scoring process, a series of tables was constructed incorporating the priority considerations identified in Table 5.5. One table was developed for each WSC sub-basin in the Province, presenting the priority considerations vertically, along with their maximum available points, and listing all the existing and proposed stations for the particular WSC division across the top.

In order to determine the maximum available points for each priority consideration, team members were asked to independently assign a value to each (out of 100) according to their perceptions of the relative importance of each. In most cases these values clustered closely around a mean, which was the value selected for the audit. Where significant divergences of opinion were encountered, team members were asked to discuss their reasons and arrive at a consensus score. The resulting scoring structure based on these values appears in Table 5.5.

Once all existing and proposed stations had been organized according to WSC divisions, the actual assignment of scores to each station involved a two-phase process: first, the pre-assignment of all "objective" scores, and secondly the convening of a "Roundtable session" to review the pre-assigned scores and complete the scoring process.

Wherever possible, objective guidelines were provided to aid in the scoring process, making those elements of the task relatively straightforward. Most of the Site Characteristics considerations (Section A. of Table 5.5) fit this category, as can be seen by examining their sub-score structure and rationale in the Table. Similarly, most of the values for the Regional Importance of Water Resource considerations (Section C. of Table 5.5) were either pro-rated or weighted on the basis of existing information (e.g. HYDEX, MUNDAT, CLI, etc.) again making the process a relatively objective one.

Once the pre-assigned scoring was completed, a Roundtable session was convened, gathering all team members as well as the operators and managers responsible for the network. The purpose of the Roundtable was multi-fold:

- to review the pre-assigned scores and revise where appropriate

- to incorporate (ie. assign scores on the basis of) the results and conclusions of the background studies of physiographic-climatic zones and regional hydrology in determining the relative priority of stations for regional hydrology purposes

- to incorporate the results of the user surveys as well as the knowledge of the managers and users of the network in interpreting the relative priorities of stations for clients' needs

- to incorporate the 'intimate' knowledge of the operators in assessing the quality of stream records, as well as other perspectives which may otherwise have been missed

- to eliminate individual biases, and

- to, as efficiently as possible, incorporate all relevant considerations toward an informed, consistent assessment of the relative worth of existing and proposed stations in the network.

The fundamental tenet of the Roundtable in all respects, was to achieve consensus among participants. Because of this consensus-building approach, and the extent of information generated, and due to the integrating nature of the exercise, **the Roundtable session was regarded by all as one of the most valuable elements of the whole evaluation exercise.**

On completion of the Roundtable, the various scores were totalled to arrive at a Station Audit Score for each existing and proposed station. Table 5.6 presents the stations in order of their accumulated Station Audit Points. The following section presents an analysis of the results.

5.6 AUDIT RESULTS

5.6.1 An Interpretive Approach

The results of the Station Audit as represented in Table 5.6 comprise the integration and ranking of the relative contributions of stations to all the identified Priority Considerations.

A pure and mechanical gauging strategy based on this ranking would be to simply include as many stations as possible, in descending order of Station Audit points, as permitted by a particular budget level. For example, a network budget of $200,000, using the $3,618 unit cost figure, would permit a network comprising the first 55 stations; i.e. Saint John River at Fort Kent down to and including Saint John River at Hartland.

It is realized however, as a matter of practicality, that the operating agencies will regard certain Priority Considerations as non-discretionary (i.e. must be satisfied) and others as relatively more discretionary depending on the resources available. The incorporation of these "constraints of practicality" requires an interpretation of the results; an interpretation which achieves a realistic compromise between the purely analytical results and the mandated requirements of the operating agencies.

TABLE 5-6

PROVINCE-WIDE STATION RANKING BY STATION AUDIT SCORE

	STATION		STATION AUDIT POINTS
1	1AD002W	SJR FT KENT	149
2	1AE001W	FISH RIV	145
3	1BJ007W	RESTIG R RFTWG	107
4	1AK001W	SHOGOM STR	107
5	1BJ010W	MIDDLE R	106
6	1BD001W	SUNIRAM R	105
7	1BJ012W	EEL R DUNDEE	104
8	1AP004W	KENDSIS R	104
9	1BU003W	TURTLE CRK	103
10	1AK004R	SJR BLW MACTAD	102
11	1BJ009R	WALKER BR	102
12	1AP0P1W	TROUT CR	98
13	1BJ003W	JACUET RIV	96
14	1AK003W	SJR FRDTON	95
15	1AJ003W	MEDUXNE RIV	95
16	1AR005R	S CROIX BAR	93
17	1BJ011W	NIGADOO R	92
18	1AF002R	SJR GRDFLS	89
19	1AD003W	ST FRANCIS	89
20	1AD0P1W	MUSQUASH R	87
21	1AR004R	S CROIX VAN	87
22	1AR006W	DENNIS ST	87
23	1AP005W	SJR ST JOH	86
24	1AD001W	LEPREAU R	86
25	1AR013W	GRND FALLS	86
26	1AH0P1W	ODELLACH R	85
27	1AK008W	EEL RIV	85
28	1AD004W	SJR EDMUN	83
29	1AP003W	SJR OK PT	83
30	1AJ001R	SJR ESTFLORVL	83
31	1AR009W	GRND LK FSTCY	83
32	1AL002W	WASHWK RDURH	82
33	1AR010W	SPEDLK STCROX	82
34	1AF007W	GRAND RIV	81
35	1AJ009W	SJR SIMONDS	80
36	1AF003R	GREEN RIV	80
37	1AF0P2W	IROQUOIS R	80
38	1AR011R	FRST CTY STR	80
39	1AR012W	CHAMCOOK STR	80
40	1AF01PW	SIEGAS R	79
41	1BE001W	UPSALQUI R	79
42	1BD0F1W	S BR RENUS	79
43	1BJ001W	TETAGOUC R	79
44	1AK0P1W	KESWICK R	79
45	1AD0F1W	CORBETT BR	78
46	1AH005W	MAMOZEKL RIV	77
47	1BU002W	PTITCODC R	77
48	1AK007W	NACKAWIC R	77
49	1AG003R	ARSTK RIV	76
50	1BV0P2W	RATCLF BR	76
51	1AP002W	CANAAN R	74
52	1AH001W	NW GROM RIV	74
53	1AG002W	LMST RIV	73
54	1BU0P1W	MEMRAMK R	72
55	1AJ008W	SJR HARTL	71
56	1BC001W	RESTIG R KEB	71
57	1BK006W	40 MILE BR	71
58	1BL0P1W	UPR TRCDE	71
59	1BK0P1W	MEPESIS UPSTRM	70
60	1AJ004W	BPRESISLE ST	70
61	1BK003R	MEPESIS MEPFLS	69
62	1BL002W	RIV CARAD	69
63	1AH002W	SLMONR CSTWY	69
64	1BD003W	BARNBY R	68
65	1AJ011W	COLD STRM	67
66	1BD002W	RENOUS R	67
67	1AD002W	SJR MGRVIL	66
68	1AP0P3W	MEREPIS TRIB	66
69	1AJ010W	BEGAGUIN STR	65
70	1AL003W	HAYDEN BR	65
71	1BQ001W	NW MIRAM R	65
72	1AP0P2W	L CANAAN	65
73	1BE0P1W	SE UPSALQ R	64
74	1AD004W	JEMSEG R JEM	64
75	1BT001W	KINNR R	64
76	1AK005W	MBNASHSISROY	64
77	1AK006W	MBNASHSISFAR	64
78	1AR0P2W	BOCABEC R	64
79	1BL001W	BASS RIV	63
80	1AH001W	CASTANY BR	63
81	1AD009W	BURP MILSTRM	63
82	1AL008W	WASHWKR STAN	62
83	1AD010W	FRNCH LK LKCON	62
84	1AF006W	MEREPIS R	62
85	1AK009W	SJR AT MACTAD	61
86	1BL0P2W	TABUSIN R	59
87	1BT0P1W	TANTRAM R	59
88	1AD003W	GRND LK WCSTLCR	59
89	1AQ002R	MAGAG R LMCR	59
90	1AQ007W	MAGAG LK	59
91	1AF0P3W	QUISIBIS R	58
92	1BB0F1W	KEDGEWICK R	58
93	1AQ009W	L UTOPIA CNL	58
94	1BF0F1W	TUADOOK R	57
95	1BA0F1W	GOUNAMITZ R	56
96	1BD004W	BARIBG R	56
97	1BL003W	BIG TRCDE R	55
98	1BR0F1W	KOUCH UPSTR	55
99	1AR0F1W	DIGDEGUASH R	55
100	1BN0P2W	CAINS R	54
101	1BS001W	COAL BR R	54
102	1BV006W	PT WOLF R	54
103	1AQ008W	PISKAHEG R	53
104	1BF001W	LTL SUNIRAM R	51
105	1AH002R	TRO RILBRK	49
106	1AH003R	TRO PLSRK	49
107	1AL004W	NRWS MTN BR	48
108	1BN0F1W	SW MIRM FKS	48
109	1BN0F1W	CAINS RDNST	48
110	1BV0P3W	SNEPODY R	48
111	1BR001W	KOUCHIBGC R	46
112	1AH004R	TRO NRWS	44
113	1BV0F1W	BIG SAM R	41
114	1AF008W	SJR GRNDFLS	33

5.6.2 Identification of Network Objectives

In order to undertake this interpretation of the results, the various Priority Considerations identified in the Station Audit exercise have been grouped into six sets of Network Objectives ranging from what was considered the least discretionary to the most discretionary:

Formal Commitments	- 15 stations
Long-Term Index	- 21 stations
Minimum Regional Hydrology Coverage	- 54 stations
Special Regional Hydrology Needs	- 83 stations
Optimal Regional Hydrology Coverage	- 85 stations
Client Needs Not Met By Other Objectives	- 7 stations

Formal Federal and Provincial Commitments, are those for which the operating agencies have obligations under formal agreements, treaties, etc. **In this sense, they are non-discretionary.** They typically involve site-specific monitoring and hence are most often operational rather than regional hydrology stations.

The implementation of a national **Long-Term Index** of the availability of and trends in the nation's water resource base is commonly accepted as the most basic raison d'etre for government involvement in water quantity monitoring (i.e. the notion of the public good); **hence, a 'relatively' non-discretionary network objective.**

Stewardship of the water resource, however, goes beyond simply monitoring trends. It requires at least a basic knowledge of the physical relationships of the resource so that generalizations can be made. **This minimum Regional Hydrology Objective, while perhaps not quite as essential as the previous two, can still be regarded as relatively non-discretionary.** The stations required to satisfy this objective were identified in the accompanying background report on Physiographic-Climatic Zones and are shown in Chapter Three of this report.

It is recognized that some of the operating agencies' programs will have regional hydrology information requirements of a 'non-network' nature. That is, they will be for specific sites or projects (e.g. water quality studies, sediment studies, small basin relationships, etc.) rather than serving a network function per se. The objective of **Special Regional Hydrology Needs** addresses the notion discussed earlier, that such requirements are more sensibly adjoined as increments to a core network, rather than having separate numerous networks of variable consistency and

quality established for each need as it arises. In this sense, **this objective is regarded as relatively more discretionary than the previous ones.** It may also be said that, since these stations do not by primary intent serve "the network", their costs should be paid from their respective programs, thereby re-inforcing their discretionary characterization from a network perspective.

In comparison with the Minimum Regional Hydrology network, we may also consider a **Target or Optimal Regional Hydrology Network** which, in combination with mathematical and statistical techniques, will provide more than just a basic understanding of the hydrology; rather, a capability to provide hydrologic interpretations with a high degree of confidence. **Such an objective, while professionally desirable, is perhaps not as essential as the minimum coverage, and in this sense, is somewhat more discretionary,** depending on availability of resources. The 85 stations identified here include the 77 natural flow stations proposed for the Target Regional Hydrology Network, as well as 8 partially regulated stations identified by the Station Audit as useful for supplementary regional information, either for small basins or transboundary areas.

Fortunately for the Canadian taxpayer, **the sets of stations identified for the above five Network Objectives are not mutually exclusive** (recalling the earlier discussion of the multi-facetedness of the benefits of hydrologic information). For example, stations selected for the Minimum Network will also contribute to the Target Network, and will often co-incidentally serve Special Regional Hydrology Needs and a multitude of Client Needs. There is, however, a small number of stations which are so **client-specific** that they are not addressed by any of the other Objectives. **This 'residue' category of stations, since it is so client-specific and does not make any contribution to the regional hydrology network in any sense, is regarded as the most discretionary of the six identified Network Objectives.**

The specification of these six Network Objectives provides us with criteria against which performance of the network may be determined and directions may be identified for improved performance. Within a specified resource level, the greater the contribution of a particular network configuration to a desired combination of Objectives, the greater the cost-effectiveness (i.e. performance) of the network.

No attempt is made here to recommend a particular combination of Objectives. That requires a follow-up management exercise dependent on assumptions being made regarding the level of available resources and management's desired outputs from the network.

The following section does, however, present an analysis of the implications for the network of a range of varying assumptions. Managers of the network will be able to use this analysis to determine the potential impacts of their decisions.

5.6.3 Alternative Network Scenarios

Using the "raw" Station Audit results from Table 5.6, seven different Network Scenarios have been developed using various combinations of Objectives. These Scenarios are described below and are illustrated in Figure 5.1 (The use of 'partial' boxes in the figure illustrates the mutually inclusive nature of the Objectives, wherein satisfaction of one may coincidentally address others. Where this occurs, the extent to which the coincidental objective is addressed is shown in percentage terms):

Scenario E- is the Existing Network, comprising 85 stations.

Scenario P1- uses the combined ranking of the 114 existing and proposed stations from Table 5.6 and imposes a status quo budget constraint. The result of focussing on the cost constraint alone, rather than on achievement of any of the six Objectives, is reflected by partial boxes showing across the board for this Scenario in Figure 5.1.

Scenario P2- is a "bare bones" proposal focussing only on the three least-discretionary Objectives: Formal Commitments, Long-Term Index and Minimum Regional Hydrology. It comprises 72 stations.

Scenario P3- also includes the mandated Formal Commitments and Long Term Index, but proposes the Target or Optimal level of Regional Hydrology coverage rather than the Minimum. It comprises 99 stations.

Scenario P4- supplements the "bare-bones" P2 proposal with additional discretionary stations in order of Station Audit points up to the status quo level; i.e. 85 stations.

Scenario P5- again covers all the bare-bones focii: Minimum Regional Hydrology, Formal Commitments and Long-Term Index, and additionally addresses any remaining Special Regional Hydrology Needs not previously addressed by those three objectives. It comprises 102 stations.

Scenario P6- is similar to the P5 proposal except that the broader Optimal Regional Hydrology Network is substituted for the Minimum. This Scenario comprises 107 stations.

Scenario P7- is the "catch-all" Scenario. It addresses all of the five basic Network Objectives plus the 'residue' category of Client Needs not met by Other Objectives. It comprises 114 stations, which is the sum of all existing and proposed stations.

In addition to Figure 5.1, Table 5.7 and Figure 5.2 have also been developed to examine the implications of the Alternative Network Scenarios. Table 5.7 summarizes:

- the change in benefits, relative to the Existing Network (E), as represented by station audit points, for the full range of the proposed scenarios;

- an appropriate gauging strategy for each, in terms of the number of existing stations to be kept, number to be closed and number of proposed stations to be added;

FIGURE 5-1

GAUGING STRATEGY IMPACTS ON NETWORK OBJECTIVES

SCENARIO	NETWORK OBJECTIVE: Minimum Regional Hydrology Network Requirements	Optimal Regional Hydrology Network Requirements	Special Regional Hydrology Requirements	Formal Federal/ Provincial Commitments	Long Term Index Stations	Client Needs Not Met by Other Objectives
P-2	■	◪ (68%)	◪ (64%)	■	■	[ ]
E	◪ (69%)	◪ (68%)	◪ (70%)	■	■	◪ (86%)
P-4	■	◪ (79%)	◪ (79%)	■	■	[ ]
P-1	◪ (82%)	◪ (77%)	◪ (81%)	◪ (87%)	◪ (95%)	◪ (43%)
P-3	■	■	◪ (90%)	■	■	[ ]
P-5	■	◪ (94%)	■	■	■	[ ]
P-6	■	■	■	■	■	[ ]
P-7	■	■	■	■	■	■
Number of stations needed for objective:	54	85	83	15	21	7

Legend:

■ Scenario fully addresses network objective.

◪ Scenario Partially addresses network objective (per cent).

[ ] Scenario does not address network objective.

- the change in the total station configuration over the range of proposed scenarios;

- the total cost of the network for each scenario, using the average unit cost of $3,618 per station; and

- the change in cost relative to the status quo level of resources, in both actual and percentage terms.

Figure 5.2 illustrates these implications in a benefit-cost context. Appendix B provides the detailed station-by-station gauging strategy implications for each Scenario. The following section provides an interpretation of the results.

TABLE 5-7

SUMMARY OF PROPOSED NETWORK SCENARIOS

SCENARIO #	Total Station Audit Points ,(E ±)	Existing Stations Kept	Existing Stations Closed	Proposed Stations Added	Total Stations, (E ±)	TOTAL COST ($3618 X # of Stations)	Change From Status Quo $	Change From Status Quo %
P 2	5515 (-940)	55	30	17	72(-13)	260,496	-47,034	-15
E	6455	85	0	0	85	307,530	0	0
P 4	6690 (+235)	65	20	20	85	307,530	0	0
P 1	6824 (+369)	69	16	16	85	307,530	0	0
P 3	7460 (+1005)	72	13	27	99 (+14)	358,182	+50,652	+17
P 5	7647 (+1192)	75	10	27	102 (+17)	369,036	+61,506	+20
P 6	7964 (+1509)	79	6	28	107 (+22)	387,126	+79,596	+26
P 7	8364 (+1909)	85	0	29	114 (+29)	412,452	+104,922	+34

SCENARIO EXPLANATION:

E - Existing Hydrometric Network.

P1 - Proposed network consisting of existing and proposed stations prioriZed by Station Audit scores and limited to current (status quo) level of resources, i.e. 85 stations @ $ 307,566 p.a.

P2 - Proposed network consisting of existing and proposed stations meeting minimum regional hydrology network requirements,formal federal and provincial committments,and long term index station needs.

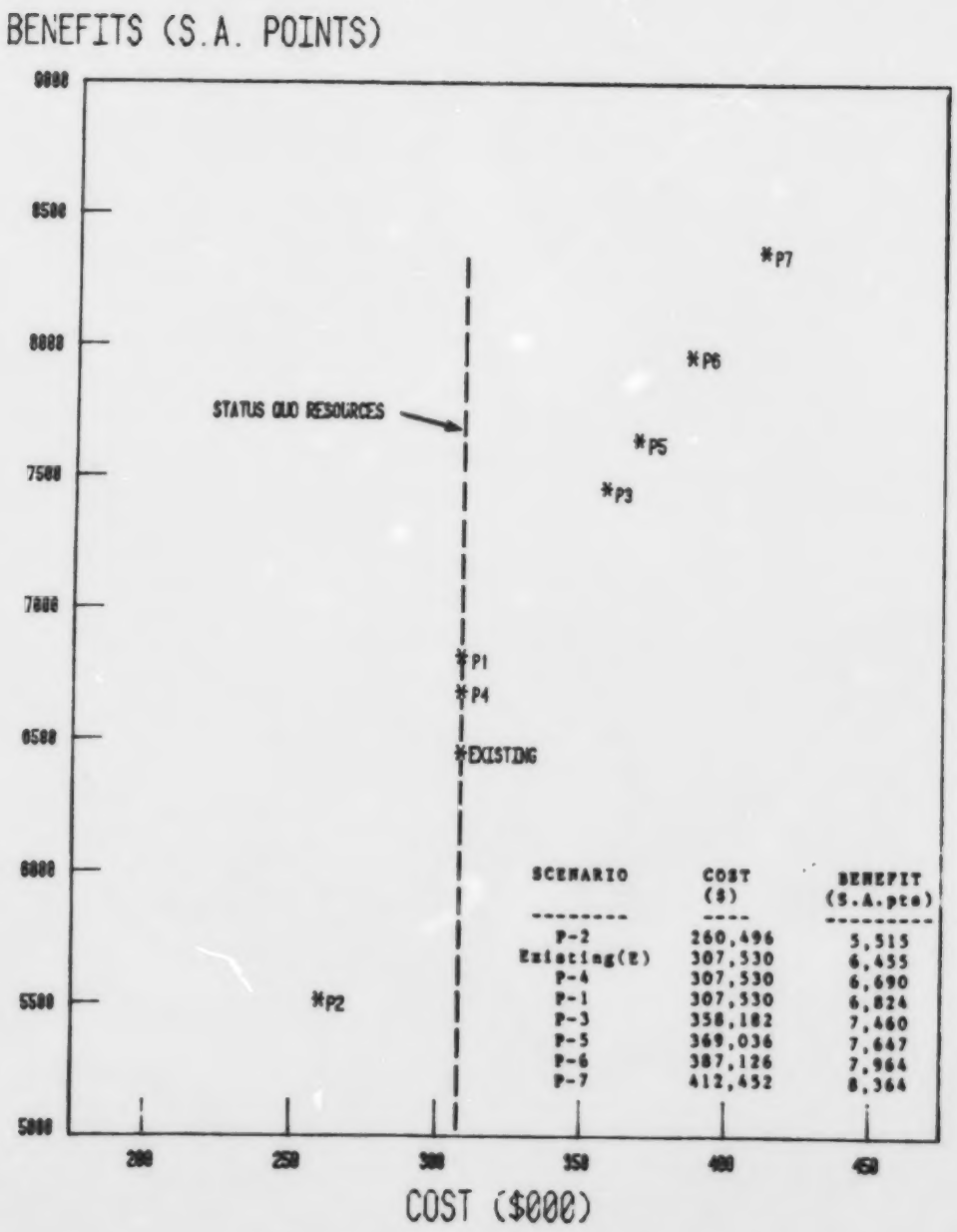
P3 - Proposed network consisting of existing and proposed stations required for optimal regional hydrology network coverage,formal federal and provincial committments,and long term index stations.

P4 - Proposed network which meets the same requirements as P2 and permits additional stations prioriZed by Station Audit scores up to the current level of resources.

P5 - Proposed network consisting of existing and proposed stations meeting minimum regional hydrology network requirements,formal federal and provincial committments,long term index station needs ! and supporting special regional hydrology needs,studies,and Jurisdictional requirements.

P6 - Proposed network consisting of existing and proposed stations required for optimal regional hydrology network coverage,formal federal and provincial committments,long term index station needs ! and supporting special regional hydrology needs,studies,and Jurisdictional requirements.

P7 - Proposed network consisting of existing and proposed stations required for optimal regional hydrology coverage and all of the identified needs, i.e.includes all existing and proposed stations.



SCENARIO	COST ($)	BENEFIT (S.A.pts)
P-2	260,496	5,515
Existing(E)	307,530	6,455
P-4	307,530	6,690
P-1	307,530	6,824
P-3	358,182	7,460
P-5	369,036	7,647
P-6	387,126	7,964
P-7	412,452	8,364

Figure 5-2 Relative Benefits and Costs of Network Scenarios

5.7 SUMMARY

Using the results of the Station Audit Exercise, a number of Proposed Network Scenarios were developed to address various combinations of Network Objectives. Each implies a shift in the level of benefits derived from the network, as represented by accumulated Station Audit points, and as well has implications for cost. On the basis of this analysis, utilizing Figures 5.1 and 5.2 and Table 5.7, a number of conclusions have been drawn. These are presented below:

(i) It is evident from Figure 5.1, that the Existing Network focuses more heavily on the 'mandated' and 'other client' dimensions than on the regional hydrology. None of the Regional Hydrology Objectives (Minimum, Optimal or Special) are fully addressed by the Existing Network. **In fact, only 68 percent of the stations required for the Minimum Regional Hydrology coverage are addressed by the Existing Network. This is especially interesting in view of the fact that, as pointed out in Chapter Three, three of the existing stations were identified as redundant for regional hydrology purposes** - a classic example of Langbein's warning: a network which is both redundant and deficient at the same time. This imbalance of supply and demand illustrates itself in Figure 5.2, where it is evident from the location of Scenario P4 relative to the Existing Network, that **increased benefits can be derived without any additional operating costs being incurred.** This is accomplished by re-targetting the network to higher priority stations.

(ii) Figure 5.2 illustrates that movement upward along the benefit scale represents an increase in total utility of the network as determined by a weighted ranking process. **It is important to note, however, that such movement may not necessarily represent an increase in our ability to achieve a specific Network Objective.** For example, although Scenario P1 exceeds P4 in level of benefits per se, Figure 5.1 shows that if management specified that the Formal Committments Objective must be met in full, the higher valued P1 Scenario would not be sufficient, as it only adresses this particular Objective to the extent of 87 percent.

(iii) The range of 'reasonable' alternatives for the New Brunswick Hydrometric Network extends from a lower-end scenario (P2) to an upper-end Scenario P7. P2 just adequately addresses the Regional Hydrology coverage for the Province as well as the

mandated responsibilities under Formal Commitments and for Long-Term Index monitoring. (P7) addresses all existing and proposed needs, including optimal coverage of the Regional Hydrology. **This range extends from a reduced cost of 15 percent for P2 (72 stations) relative to the status quo (85 stations), to an increase of 34 percent for P7 (114 stations).** The in-between scenarios represent interim network milestones which may be achieved, depending on the level of resources available and specifications of management's desired network outputs.

(iv) The reality of the results of the Station Audit exercise is that operational stations which do not concomittantly contribute to the regional hydrology network tend to fall towards the lower end of the scale and will consequently tend to be those identified for closure when resources are limited. It is not, however, being argued that such stations are unimportant to the client or purpose for which they were established.

(v) It became apparent over the course of the Station Audit exercise that concerns with regard to the variability of the quality of record at station sites may not have been adequately addressed. The comment was made that "bad data is worse than no data at all". It became further apparent, however, that there was little information available on which to base any conclusions about this variability: whether lower-rated records were due to site controls or physical anomalies; whether the data could be improved via minor adjustments; or whether the site is simply inappropriate and should be abandoned.

(vi) Finally, given that any prescriptions for improved network performance based on the preceding analysis can only be accomplished by physically closing some stations and constructing others, it is realized, of course, that such adjustments will not happen overnight. Rather, **improvements will only be accomplished by an orderly replacement of lower priority stations with higher priority stations within the context of a capital replacement program.** The extent of the adjustment will of course depend on the resources available and on the specification of particular Objectives.

6.0 MAIN FINDINGS AND RECOMMENDATIONS

6.1 GENERAL

This assessment was carried out with the intent of evaluating the New Brunswick network from a number of different perspectives: hydrological and technical; socio-economic; and from the data user's point of view. The current conditions of restraint and the emphasis on downsizing in government activities were also borne in mind throughout. But from all these perspectives, the overall assessment was that the New Brunswick hydrometric network is not overly indulgent. In fact, for some important mandates, which require the support of a Regional Hydrology information base, significant gaps do exist. Some opportunties for network improvement through re-allocation of existing resources were identified. These offer possibilities for network adjustments without incurring additional operational costs, while at the same time recognizing that over the long-term, some additional needs should be met if basic network objectives are to be satisfied. Finally, alternative scenarios were developed that will assist network managers to assess the impacts of changes in network resource allocations that may be necessary. The following sections outline the main findings of each of the main areas of investigation. Subsequently, the recommendations for network management that have been drawn therefrom are summarized.

6.2 ASSESSMENT OF USER NEEDS

An appreciation of user needs for hydrometric data is essential for planning, since it is only through application and use that the data attains its value and worth. A quite extensive user survey was carried out to assist in identifying these needs. Usage was further elaborated through the "Roundtable" audit process attended by members of the various Federal and Provincial agencies most closely associated with the network.

The surveys indicated that a high demand exists for hydrologic data and information among professional users. Approximately 90% of respondents interviewed indicated a frequent use of data, at least once a month.

The data is required to a high level of accuracy. Eighty-five percent of all respondents indicated a desire for an accuracy of $\pm$ 10 to 20% in their work. To a large extent, this reflects the importance of the planning, design, and construction decisions that are based upon the use of data, and the fact that estimations and data transfers are always accompanied by limitations in their use.

The foremost users of hydrometric data in the province include government agencies, consultants, power utilities, and academic institutions. Except for the primary operating agencies, however, most users were either unable to or preferred not to identify site-specific requirements. Instead, they indicated a reliance upon a representative regional hydrology network, with a capacity for data transfer to meet unanticipated needs.

The foremost applications of hydrometric data at present are for estimates of streamflow at ungauged locations (i.e. regional hydrology), flow forecasting, and an amalgam of fisheries-environmental-water power purposes. Emerging issues and priorities such as climate change, toxics management (Canadian Environmental Protection Act requirements) and sustainable development will of course require extension of a reliable, continuous hydrology information base into the future.

Among non-professional users, a low awareness of hydrometric data and publications exists. In part, data and publications have been geared towards the professional user needs that are considered more pressing and urgent. But this does provide a marketing opportunity to develop the user-base more fully.

User suggestions for network and program improvements included:

- poor station coverage in central New Brunswick
- a lack of stations on small watersheds
- insufficient sediment station coverage
- inadequate data transfer capabilities
- better integration of networks and data bases (eg. hydrometric and meteorological) to facilitate data retrieval and user analysis
- increased emphasis on interpreted information to supplement the basic data
- data availability in more convenient formats
- provision of related data, such as watershed parameters for monitored basins, to supplement the basic data.

Some of these same needs were identified in the hydrological analysis portions of this study.

Other themes, particularly the desire for interpreted products, are persistent ones that are common to many user surveys.

6.3 REGIONAL HYDROLOGY ASSESSMENT

Operational hydrometric requirements, which are normally site-specific and real-time, can in most cases only be met by the operation of a gauging station. Regional needs are the converse and can be met by the combination of representative sampling and data transfer techniques. Regression analysis was selected as the most appropriate data transfer technique and an assessment was undertaken to determine appropriate sample size. This technique is the simplest and most widely applied form of data transfer.

The assessment was carried out by referencing the basic physiographic and climatic zones in the province that might logically be assumed to influence streamflow runoff, as well as by assessing the information content of the present records and network. This provided a basis upon which to judge minimum network requirements as well as a target network requirement for defining hydrologic conditions in a more satisfactory manner.

With respect to the minimum requirement, considering the physiographic and climatic diversity of the province, the larger basins appear to be adequately covered by the present network, but the small to medium size basins are clearly under represented. Some of the physiographic-climatic zones are not measured at all, and therefore no basis exists for establishing their true hydrologic conditions. Of the 54 station sites identified for the Minimum Regional Hydrology Network, only 37 are addressed by the existing network.

Furthermore, the Minimum Network cannot be regarded as anything more than a collection of stations assumably representing areas of relatively homogeneous hydrologic characteristics, and constitutes the "least credible" capability for the provision of regional hydrology information for the province.

In order to provide a more reliable regional hydrology information base, spatial representation must actually be tested for statistical significance and a more enhanced database (ie. gauging station network) is required to support this capability. A minimum of 10 stations per representative hydrologic unit was assumed to provide sufficient degrees of freedom for statistically significant data transfer functions to be developed. Application of this criterion to the 16 physiographic-climatic zones identified for the Minimum Network would have required a minimum of 160 stations; a 100 percent increase over the present network. Realism prevailed, however,

and a revised approach was employed for the determination of a reduced number of representative hydrologic units.

To accomplish this task, the regional hydrology network was assessed on its ability to transfer the 1:100 year recurrence interval flood flows, the 1:20 year mean annual and the 1:20 year 10-day mean low flows. It was assumed that these three parameters would reflect the typical needs for streamflow information in the Province.

Assessing the accumulated records and the existing stations, it is clear that there is at present a capability to provide a reasonable estimate of annual runoff and yield for most locations. However, this is always the easiest hydrologic parameter to estimate. Estimates based upon the present network typically varied from 10% to 14% accuracy. The standard in other areas appears to be closer to $\pm$ 5 per cent.

Low flow conditions are important for water supply, wastewater disposal, and environmental management purposes. Estimating this parameter using the present New Brunswick network involves errors of as much as 30% to 54%. Although comparable to errors found in other studies, the implications are still that low flow assessment in New Brunswick is difficult.

In terms of flood flow analysis, more work has been done, and estimates of peak flood flows have been made with an accuracy of $\pm$ 20%. This may be considered just satisfactory for many purposes, but as some users pointed out, a greater accuracy of estimation is required for other purposes.

Attempts were made in this study to establish estimating techniques for daily flows at ungauged locations. Daily flows are needed for the design and operation of many types of hydraulic control structures. In this case, meaningful relationships were not established and it was concluded that only hydrometric stations can satisfy these operational needs.

In all of these analyses, small watersheds, less than 250 km^2, consistently appear as an area where more hydrometric and meteorological data is required. Furthermore, the lack of records in central New Brunswick also appeared as a deficiency.

These foregoing technical analyses were carried out to try to establish the reliability with which a typical user could estimate hydrologic conditions at ungauged locations in the province. The overall findings indicated that considerable uncertainty does exist, which can only be addressed through a combination of hydrologic research and continued data collection activities. Of the 77 station sites identified for the Target Regional Hydrology Network, only 51 are addressed by the existing network.

6.4 HYDROMETRIC TECHNOLOGY AND OPERATIONS

A review of current developments in hydrometric technology was carried out to identify any cost effective alternatives worthy of evaluation and implementation. Some findings of this exercise were as follows:

There is an increasing trend towards automation of hydrometric stations, taking advantage of recent developments in sensors, telecommunications, satellites, and low-cost microprocessors. This offers potential increases in cost-effectiveness of both field and office procedure, and forms the backbone of long-range WRB planning at the present time.

Servo-manometer systems experience more problems and are less reliable than float-actuated devices, based upon actual field experience in New Brunswick. Electronic stage sensors and related data acquisition systems are less costly than conventional means and will reduce record loss and operational effort.

Operational procedures require continued development to meet network and user needs. Procedures for flow measurement under ice conditions are considered to be a high priority in this regard.

The need for river observers, reporting on ice conditions or for flow forecasting, remains strong. However, the number of gauge attendents will likely decrease as better equipment and procedures become available.

The use of seasonal hydrometric stations is not considered feasible in most instances, since operating costs remain high but data collected is substantially reduced. High runoff may occur, in New Brunswick, at any time of the year for some basins. Seasonal stations, however, may be appropriate for specific project applications.

6.5 EVALUATION OF GAUGING STRATEGIES

An evaluation of individual stations and alternative network strategies was carried out in this study. A pragmatic station "audit" process, based upon an integration of several technical and non-technical criteria, was first applied to establish a rough ranking or prioritization of existing and proposed hydrometric stations. These results, along with stated hydrometric program objectives, were then used to identify and assess a number of alternative network development scenarios. Guidelines for short-term and long-term planning of the network were established in this fashion.

It was noted that the benefits of a regional hydrology network cannot be directly quantified and apportioned. This is because of the multi-purpose aspects of the usage of the data, and the fact that each separate use may require a different level of accuracy. Particular stations may, and more often than not, do simulaneously serve many of these uses at one time. The best that could be achieved in this study was to consider carefully those factors, both technical and non-technical, that contribute to the quality and utility of a hydrometric station and determine priorities on the basis of the extent of these contributions.

Despite the inability to quantify benefits, the concept of hydrometric data and information as serving a high level of "public good" is considered to be well founded. From the point of view of resource stewardship, meeting unforeseen needs, and the proper design of the province's physical infrastructure, comprehensive hydrometric data is clearly essential.

Additionally, it is recognized that public savings are realized not only vis-a-vis economies of centralization associated with a core network, but also in terms of reduced data costs for public infrastructure. These savings can range from as little as 75% of the hydrologic design cost for a small project (eg. a secondary highway bridge), to substantially greater magnitudes for larger undertakings. The Provincial Government alone expends $40 million annually for transportation and waterworks infrastructure requiring hydrologic design data. Considering the implied savings, the $300,000 annual operating cost of the hydrometric network appears a modest investment.

The pragmatic station audit process developed and applied in this study was found to be very useful, both in terms of assessing stations and providing a framework for integrating the views of many different participants. The process is considered to be, first and foremost, a tool for assessing the impacts of management decisions rather than a definitive method of selecting the "right" combination of stations. It was applied with judgement and interpretation, not arbitrarily based solely upon benefit-point scorings.

The audit process indicated that the existing network is focussed heavily upon meeting mandated and operational needs to the detriment of regional hydrology. But throughout the evaluation process, regional hydrology emerged as perhaps the most important purpose towards which the network should be designed.

It was noted over the course of the audit exercise that the quality of records does vary from station to station and that "problem" stations can impact on any proposed gauging strategy. It was also noted, however, that little information was available at present to identify appropriate solutions for these problem sites.

The overall assessment of the network points to a mature network, which is reasonably well-targeted, not excessive and in fact deficient in some respects. Some deficiencies can be addressed via re-allocation of resources in the short term; others can only be achieved by selective expansion of the network over the long term.

The methodology applied in this evaluation overcomes the historical tendency to simply augment the network in response to incremental needs. Technical, user, and socio-economic concerns were balanced together to determine sets of network objectives against which network performance can be assessed. Appropriate gauging strategies were identified for the achievement of these objectives.

The methodology is flexible, in that objectives can be modified and assumptions revised, based on management priorities and the results can be readily identified. The evaluation framework is a general one which is easily adapted and applied to most situations. The principal recommendations based on the findings of this assessment are presented below.

6.6 RECOMMENDATIONS

1) It is recommended that the Coordinating Committee establish (with reference to management priorities) a set of long-term and short-term objectives for the network, utilizing the findings presented here:

a) The long-term objectives would be in the direction of Scenario P6 which includes coverage for:

- the "optional" or Target Regional Hydrology Network
- Formal Federal-Provincial commitments
- the Long-Term Index Network, and
- any remaining "special" regional hydrology needs not covered by the above.

Although a portion of this could be accomplished by a re-allocation of existing resources, full achievement of P6 would require a 26% increase over the existing resource level. Scenarios P3, P4 and P5 represent interim milestones.

b) The short-term objectives should be to at least ensure the "bare bones" network requirements are met:

- the Minimum Regional Hydrology Network
- Formal Federal-Provincial Commitments
- the Long-Term Index Network.

This could be accomplished by moving towards Scenario P4 which meets these requirements by making re-allocations from lower to higher priority sites within the existing resource level.

c) The lowest priority stations (ie. those first available for re-allocation) should be those seven (7) stations comprising the difference between Scenarios P6 and P7. These stations are so client-specific that they do not contribute to any of the other network objectives.

d) Any tendency toward downsizing of the network should be carefully assessed against the loss in public benefits attributable to an effective regional hydrology network and in terms of the potential for reduced service to the public.

2) It is recommended that a Federal-Provincial Network Evaluation and Planning Subcommittee be established for the purpose of overseeing the implementation of network planning recommendations on an ongoing basis. The Terms of Reference for this working group (which would report to the Agreement Coordinators) would include:

- ongoing communication with users to make assessments of changing needs,

- network analysis, and joint hydrologic studies,

- network technology and automation

- investigations of record quality including existing stations,

- integrated network planning vis-a-vis atmospheric, water quality, and ground water programs, and

- most importantly, the preparation of an implementation plan for network adjustments by the fall of each year.

3) It is recommended that, prior to undertaking any station closures associated with any implementation plan, the operating costs of these stations should be offered to interested clients.

4) It is recommended that Regional Hydrology needs especially in Northern New Brunswick be more strongly considered in operating the networks, and that continued efforts be made to refine the regional hydrology network through improved measurement and data transfer techniques. Regular evaluations should be carried out on individual stations to assess the quality of record and its role in defining regional hydrologic conditions. An immediate

overview investigation of sites with "problem" records is required prior to implementing any network scenario. Existing network deficiencies with respect to small water sheds and coverage in central New Brunswick should be addressed notwith standing the desireability of good data transfer techniques, it is recognized that for many purposes, such as daily flows for operational purposes, legal requirements, and some project design, only hydrometric measurements will satisfy the needs of many users.

5) It is recommended that integrated planning of hydrometric data collection and related environment data programs be pursued, to the extent feasible and practical. By this we mean that hydrometric planning incorporate the needs of the meteorological, water quality, and ground water programs, and vice versa. The co-location of equipment and coordination of certain field activities is now taking place. The location of water quality stations, for example, to take maximum advantage of available hydrometric data would be another good example. In addition, many users require hydrometric,groundwater, meteorological, and water quality data in the same basin in order to address specific water resource problems and issues. From this prespective, information to show what data is available, where it is to be found, and how to access it would be beneficial. New technology for storing and disdeminating data, such as compact disks and optical disks, is a very promising way to meet these user needs and is being investigated by the WRB.

6) It is recommended that efforts be made to foster increased research and development with respect to the problems of flow measurement under ice conditions.

7) It is recommended that preparatory work towards full automation in data collection be undertaken for increased automation in data collection activities, including: a pilot project to determine the feasibility of using fixed ultrasonic velocity measurement devices, and planning for the use of the Canadian direct readout ground station data reception facilities and implementation of electronic sensors and data acquisition equipment. It is also felt that electronic stage sensors should be installed at all new stations rather conventicual pressure manometers.

8) It is recommended that a marketing strategy be developed and implemented to broaden the user base. Increased user interaction and communication should be facilitated by means of annual workshops and an annual newsletter containing relevant program and product information, including any updates and network changes. The provision of data in micro-computer formats and an optical disk offer very promising methods of increasing data accessibility and applications.

9) In response to identified user needs, it is recommended that more interpreted information, designed to assist users of hydrometric data, be prepared and distributed on a regular basis. Information such as station evaluations, regional or basin assessments of extreme flows, summarized data with graphics, supplementary data on monitored watersheds and regional, basin, or technical "fact sheets" are suggested items.

BIBLIOGRAPHY

Acres Consulting Services Limited, Regional Flood Frequency Analysis, Canada-New Brunswick Flood Damage Reduction Program, September, 1977.

Acres Ltd., An Apprasial of Power Development Potential of the Saint John River Basin, 1973

Acres Ltd., Economic Evaluation of Hydrometric Data, 1977

Acres Ltd., Water Supply Constraints to Energy Development - Phase IV, 1985

Acres International Ltd. Hydrologic Design Methodologies for Small-Scale Hydro at Ungauged Sites - Phase II, Inland Waters Directorate-Atlantic Region, executed for Energy, Mines and Resources, Canada, 1985.

Attanasi, E. D., Kanlinger, M.R., The Economic Basis of Resource Information Systems: The Case of Streamflow Data Network Design, Water Resources Research, Vol. 13, No. 2, April 1977

Benson, M.A. and Matalas, N.C., Synthetic Hydrology Based on Regional Statistical Parameters', Water Resources Research, v. 3, no. 4, 1967, p. 931-935.

Bostock, N.S., Physiographic Regions of Canada. Geological Survey of Canada, Map 1254A, Ottawa, 1970.

Boyer, D., Gridley, N.C., and McCullough, B., Hydrometeorological Network Evaluation, New Brunswick and the Saint John River Basin, Civil Engineering Department, University of New Brunswick, Term Papers, May, 1978.

Brandon, L. V., Water Resources Data and Development in New Brunswick, Department of Natural Resources, Fredericton, March, 1967.

Canadian National Committee, Hydrological Mapping. Proceedings of Workshop seminar. Secretariat of Canadian National Committee. The International Hydrological Decade, Ottawa, 1969.

Chang M., Lee R., Dickenson, W.H., Adequacy of Hydrologic Data for Application in West Virginia, West Virginia University, Water Research Institute, 1976

Church, M., Kellerhals, R., On Hydrological Data Needs in Canada, Canadian Water Resources Journal, Vol. 5, No. 4, 1980

Collier, E.P., and Nix, G.A., Flood Frequency Analysis for the New Brunswick Gaspe Region, Technical Bulletin No. 9, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 1967.

Condie, R., The Three Parameter Lognormal Distribution Applied to Regional Flood Frequency Analysis by the Index Flood Method, Environment Canada, Proceedings of the Technology Transfer Workshop, Series No. 2, 1980, pp. 345-353.

Dalrymple, T., 'Flood Frequency Analysis', Manual of Hydrology: Part 3, Geological Survey Water Supply Paper 1543-A, 1960.

Davis, D.R., Duckstein, L., Krzysztofowing, R., The Worth of Hydrologic Data for Nonoptional Decision Making, Water Resources Research, Vol. 15, No. 6, December 1979

Dawdy, D.R., Kukik, H.E., Close, E.R., Value of Streamflow Data for Project Design - A Pilot Study, Water Resources Research, Vol 6, No. 4, August 1970

Doyle, W. H., Jr., Shearman, J.O., Stiltner, G.J., and Krug, W.R., A digital model for streamflow routing by convolution methods. U.S. Geological Survey Water-Resources Investigations Report 83-4160, 1983.

Draper, N.R., and Smith, H., Applied Regression Analysis, John Wiley & Sons, Inc., Toronto, 2nd edition, 1981.

Environment Canada and New Brunswick Department of Environment, Hydrometric Network Review for the Province of New Brunswick, October, 1979.

Environment Canada and New Brunswick Department of Municipal Affairs and Environment, Flood Frequency Analyses, New Brunswick, April, 1987.

Environment Canada (Regional Screening and Coordinating Committee), Atlantic Region Projects Registered May 1985 - July 1987

Environment Canada (Water Resources Branch), Summary and Analysis of Data and Information Requests Received 1985 - 1987, Atlantic Region, July 1987

Environment Canada et al., 1979. Hydrometric Network Review for the Province of New Brunswick. (1979). Environment Canada: Inland Waters Directorate: Water Resources Branch and New Brunswick Department of Environment: Water Resources Branch, Fredericton, N.B., October, 1979. 266 pages

Environment Canada, 1983. Hydrometric Field Manual - Measurement of Stage. (1973). Environment Canada: Inland Waters Directorate: Water Resources Branch, Ottawa, 1983. (pp. 47).

Environment Canada, 1981. Hydrometric Field Manual - Measurement of Streamflow. (1981). Environment Canada: Inland Waters Directorate: Water Resources Branch, Ottawa, 1981. (pp.37).

Environment Canada (Water Resources Branch), Summary Report - Western and Northern Region Hydrometric Network Evaluation and Planning Activities, August 1986

Environment Canada, Water Resources Branch Data Dissemination Summary 1985 - 1986, December 1986

Environment Canada and Nova Scotia Department of the Environment, Hydrologic Network Review-Nova Scotia, 1985

Fontaine, R.A., Moss, M.E., Smath, J.A., Thomas, W.O. Jr., Cost-Effectiveness of the Stream-Gauging Program in Maine, U.S.G.S. Open-File Report 83-261, 1983

Haan, C.T., Statistical Methods in Hydrology, The Iowa State University Press, Ames, Iowa, 1977.

Haan, C.T., H.P. Johnson and D.L. Brakensiek (editors): Hydrologic Modelling of Small Watersheds, American Society of Agricultural Engineers Monograph No. 5, Michigan, U.S.A., 1982.

Haimes, G.G., Craig, J.A., Subvahmanian, J., The Worth of Streamflow Data in Water Resources Planning: Computational Results, Water Resources Research,Vol.15, No. 6, December 1979

Hall, F.R., Dingman, S.L., Utilization and Interpretation of Hydrologic Data with selected examples from New Hampshire, New Hampshire University, Water Resources Research Center, 1979

Harvey, K.D., Condie, R., and Pilon, P.J., Regional Flood Frequency Analysis with the Three-Parameter Lognormal Distribution. A paper prepared for presentation to the 7th Canadian Hydrotechnical Conference of the CSCE, May 27 - June 1, 1985, Saskatoon, Saskatchewan.

Informetrica Ltd., Canadian Capital Projects, September 1986

Ingledow and Associates Limited, Hydrometric Network Plan for the Provinces of Newfoundland, New Brunswick, Nova Scotia, and Prince Edward Island, for the Government of Canada, Department of Energy, Mines and Resources, December, 1970.

Institute of Hydrology, Low Flow Studies, Wallingford, Oxon, United Kingdom, January 1980.

International Standards Organization. 1974. Standard 2537, Technical Committee 113, International Organization for Standardization, Case postal 50, ch-1211, Geneve 20, Switzerland.

International Standards Organization. 1979. Standard 748, Technical Committee 113, International Organization for Standardization, Case postal 50, ch-1211, Geneve 20, Switzerland.

James, I.C.II., Bower, B.T., Matalas, N.C., Relative Importance of Variables in Water Resources Planning, Water Resources Research, Vol. 5, No. 6, December 1969

Keefer, T.N., Desktop Computer Flow Routing, American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division. v. 100, no. HY7, p. 1047-1058.

Kendall, M.G., Multivariate Analysis, Hafner Press, New York, 1975.

Kreuder, W.L., Development of Hydrometric Networks in British Columbia, Water Resources Research, Vol. 15, No. 6, December 1979

Langbein, W.B., Overview of Conference on Hydrologic Data Networks, Water Resources Research, Vol. 15, No. 6, December 1979

McMalron, T.A., Cronin, D.L.R., An approach to Marginal Economic Analysis of Hydrometric Data Collection, Water Resources Bulletin, Vol. 16, No. 3, June 1980

Mian, M.S., Regional Variation of Maximum and Minimum Flows in New Brunswick, A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in the Department of Civil Engineering, University of New Brunswick, May 1972.

Mimikou, M. and Kaemaki, S., Regionalization of Flow Duration Characteristics, Journal of Hydrology, vol. 82, 1985, p. 77-91.

Montreal Engineering Company Limited, Maritime Provinces Water Resources Study for Atlantic Development Board, January, 1969.

Montreal Engineering Co., Identification of Environmentally Compatible Small Scale Hydroelectric Potential in Atlantic Canada, Phasel - New Brunswick and Prince Edward Island, 1984

Moss, M.E., Optimum Operating Procedure for a River Gauging Station Established to provide data for design of a Water Supply Project, Water Resources Research, Vol. 6, No. 4, August 1970

Moss, M.E., Some Basic Considerations in the Design of Hydrologic Data Networks, Water Resources Research, Vol. 15, No. 6, December 1979

New Brunswick Hydrometric Network Review; Background Report No. 1 Assessment of User Needs, Feb. 1988.

New Brunswick Department of the Environment, Water Resources Branch, Bathurst Planning Region Water Resources Review, 1979.

New Brunswick Department of the Environment, Water Resources, Campbellton-Dalhousie Planning Region Water Resources Review, 1979.

New Brunswick Department of the Environment, Water Resources Branch, Edmundston Planning Region Water Resources Review, 1981.

New Brunswick Department of the Environment, Water Resources Branch, Fredericton Planning Region Water Ressources Review, 1980.

New Brunswick Department of the Environment, Water Resources Branch, Moncton Planning Region Water Resources Review, 1984.

New Brunswick Department of the Environment, Water Resources Branch, Newcastle-Chatham Planning Region Water Resources Review, 1984.

New Brunswick Department of the Environment, Water Resources Branch, Saint John Planning Region Water Resources Review, 1977.

New Brunswick Hydrometric Network Review; Background Report No. 1, Assessment of User Needs, Feb. 1988

Peters, J.E., and Ambler, D.C., Assessment of Network Operations,Atlantic Provinces District, Water Survey of Canada, Inland Waters Directorate, Halifax, Canada, 1973.

Pilon, P.J., Forecasting Spring Season Water Yield Using Multivariate Analytic Techniques', M.A.Sc. Thesis, University of Ottawa, 1981.

Pilon, P.J., Personal Communication, Water Resources Branch, Environment Canada, Ottawa, 1987.

Pilon, P.J., and Cheng, L. Statistical Package, SP. User Manual for Version i - DEC PRO Series, Inland Waters Directorate, Environment Canada, Ottawa, 1987.

Pilon, P.J., and Condie, R., Multiple Linear Regression in Hydrology, Water Resources Branch, Inland Waters/Lands, Environment Canada, Ottawa, Ontario, 1983.

Pilon, P.J., and Condie, R., Consolidated Frequency Analysis Package, CEA, Inland Waters Directorate, Environment Canada, Ottawa, 1985.

Pilon, P.J., and Thomas, W.O., Alternate Methods of Developing Streamflow Informatin, Water Resources Branch intern. Publ, 1985.

Porter-Dillon Ltd.; Summary Report on Findings of the User Survey Project, April, 1987.

Rampton, V.N., Gauthier, R.C., Thibault, J., and Seaman, A.A., Quaternary Geology of New Brunswick. Memoir 416, Geological Survey of Canada, Ottawa, 1984.

Riggs, H.C.,'Regional Analysis of Streamflow Characteristics', Chapter B3 of Book 4, Hydrologic Analysis and Interpretation, U.S. Geological Survey Techniques of Water-Reaources Investigations, 1973.

Rowe, J.S., Forest Regions of Canada. Publication No. 1300, Canadian Forestry Service, Department of the Environment, Ottawa, 1972.

Sauer, V.B., 'Unit Response Method of Open-Channel Flow Routing', American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division, v. 99, no. HY1, 1973, 179-193.

Shen, H.W., General Report - Network Design and Regional Studies

Shawinigan Engineering Company, Northwest Territories Water Resources Inventory Study, August 1982.

Shiau, S.Y., and Steingass, C., Documentation of Streamflow Accounting Program Version 2 - SAP2, Water Resources Branch, Inland Waters Directorate, Environment Canada, Ottawa, 1985.

Shiau, S.Y., and Steingass, C., Analysis of Basin Storage and Water Balance with Climatological Estimate of Areal Evaportranspiration (BSTOR), Water REsources Branch, Inland Waters Directorate, Environment Canada, Ottawa, 1985.

Solomon, S.I., Denouvilliez, J.P., Chart, E.J. Fast, Woolley, J.A. and Cadou, C.X., The Use of a Square Grid for Computer Estimation of Precipitation, Temperature and Runoff, Water Resources Research, vol. 4, no. 5, 1968.

Statistics Canada, 1981 Census of Population

Stanescu, S., Klohn, W., Design of Hydrometrical Networks and Application to Colombia

Stedinger, J.R., and Tasker, G.D., Regional Hydrologic Regression 1, Ordinary, Weighted and Generalized Least Squares Compared, Water Resources Research, vol. 21, no. 9, 1985.

Stedinger, J.R., and Tasker, G.D., Correction to Regional Hydrologic Regression 1, Ordinary, Weighted and Generalized Least Squares Compared, Water Resources Research, vol. 22, no. 5, 1986.

Stedinger, J.R., and Tasker, G.D., Regional Hydrologic Regression 2, Model-Error Estimators, Estimation of Sigma and Log-Pearson Type 3 Distributions, Water Resources Research, vol. 22, no. 10, 1986.

Thomas, D.M., Benson, M.A., Generalization of Streamflow Characteristics from Drainage-Basin Characteristics, USGS Water - Supply Paper 1975

Thomas, W.O., Jr., L.C. Cheng, and G.D. Tasker. Computer Procedures for Hydrologic Regression and Network Analysis Using Generalized Least Squares, Inland Waters Directorate, Environment Canada, 1985.

Villeneuve, J.P., Bobee, B., St. Martin, H., and Slivitzky, M., Methodologie de Rationalisation de Reseaux Hydrometriques. Bull. Sci. Hydrol., 18(4), 1973, 459-471.

Wahl, K.L., Crippen, J.R., A Pragmatic Approach to Evaluating a Multipurpose Stream-Gauging Network, USGS Water Resources Investigations Report 84-4228, 1984

Water Resources Branch, An Assessment of the Hydrometric Network of the Province of New Brunswick, Present and Future, Department of Energy, Mines and Resources, Halifax, Nova Scotia, 1966.

Watt, W.E., Wilson, K.C., An Economic Approach for Evaluating the Adequacy of Hydrologic Data

Woolhiser, D.A., Ed., Decisions with Inadequate Hydrologic Data (proceedings of the second international hydrology symposium), Fort Collins, Colorado, 1972:

World Meteorological Organization, Casebook on Hydrological Network Design Practice, W.M.O-No. 324,1972:
a) Kagan, R.L., Precipitation-Statistical Principle
b) Langbein, W.B. (abstracted from a report by Jordan, P.R. and Hedman, E.R.), Evaluation of a Stream-Gauging Programme in Kansas
c) Solomon, S.I., Multi-Regionalization and Network Strategy"
d) Dawdy, D.R., Moss, M.E., Matalas, N.C., Application of Systems Analysis to Network Design.
e) Kundin, R.D., Some Aspects of General Strategy of Hydrological (hydrometric) Network Design.

World Meteorological Organization, Cost-Benefit Assessment of Hydrological Data (Final draft of state-of-the-art workshop, November 1982.0

World Meteorological Organization, Guide to Hydrological Practices. WMO - No. 168, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1974.

APPENDICES

APPENDIX A

PREVIOUS HYDROMETRIC NETWORK REVIEWS

A. Non-Statistical Reviews

1. An Assessment of the Hydrometric Network of the Province of New Brunswick, Present and Future, Department of Energy, Mines and Resources, Water Resources Branch, Halifax, N. S., 1966.

This study was the first attempt to formalize network planning and evaluation. The study summarized the existing network, classified hydrologic regions, and identified additional gauging sites to complete a basic hydrometric network. The five distinct hydrologic regions were defined as follows:

(1) Coastal flatlands,
(2) Coastal lowlands,
(3) Northern uplands,
(4) Southwestern lakeland, and
(5) Southeastern highlands.

The study developed the idea of three types of stations; primary, secondary and special project. In conclusion, the study recommended the addition of sixteen primary stations. By 1979, six had been constructed.

2. Water Resources Data and Development in New Brunswick, L. V. Brandon, Department of Natural Resources, Fredericton, New Brunswick, 1967.

The report summarized the physiographic and hydrologic characteristics of the province of New Brunswick. It divided the province into four climatic regions; northern, southern, central and Bay of Fundy. To estimate mean annual runoff in ungauged areas, the author divided the province into the same five regions mentioned in report 1.

Using these estimates of ungauged flow, the total flow in the province was estimated at about 47 billion cubic metres per year, or 0.02 cubic metres per second/sq. km. Lastly, the author presented flow duration curves for 30 stations.

3. Hydrometric Network Evaluation, New Brunswick and Saint John River Basin, Boyer, Gridley and McCullough, Civil Engineering Department, University of New Brunswick, Fredericton, New Brunswick, 1978.

This term paper evaluated the 1978 hydrometric network against four different standards:

(1) U. N. graphs for comparative densities - the network is well above, "reasonable minimum objectve",

(2) W.M.O. tables for mininum densities - the hydrometric network is within the recommended minimum but deficient because of gauge clustering,

(3) U.S.C.E. guide formula - determined a number of streamflow gauges were in excess, and

(4) Langbein's recommendations - some stations did not sample the major climatic regions.

4. Hydrometric Network Review for the Province of New Brunswick, Environment Canada and New Brunswick Department of Environment, October, 1979.

The report concluded that until 1969 there was no systematic planning of the hydrometric network. However, an adequate hydrometric base existed in New Brunswick as of 1979. the report assessed all current stations and recommended certain network changes.

In addition to these changes the report made two major recommendations to increase network efficiency. The first emphasized the need for small basin data to support various design applications while the second suggested increased spending on the automation of data collection.

B. Statistical Reviews

1. Hydrometric Network Plan for the Provinces of Newfoundland, New Brunswick, Nova Scotia and Prince Edward Island, Ingledow and Associates Ltd., December, 1970.

The study was intended to aid in the establishment of a hydrometric network to provide uniform and adequate coverage of the region. A second objective was the establishment of regional equations for estimating mean annual streamflows on ungauged streams. This involved setting up of a database of meteorologic, physiographic and streamflow data on a ten kilometre square grid.

It also involved delineation of hydrologic zones using both statistical and non-statistical approaches. Both approaches led to the same zones:

(1) Northern,
(2) Southern, and
(3) Fundy coast.

Recommendations included a call for closer coordination in the planning of the meteorologic and hydrometric networks.

2. Regional Variation of Maximum and Minimum Flows in New Brunswick, M.S. Mian, Department of Civil Engineering, University of New Brunswick, 1972.

This study set out to develop representative curves of flood and drought frequency for five regions of New Brunswick. Statistical techniques indicated that the Pearson Type III distribution was best suited for high flow estimation.

In addition, standard linear regression correlated maximum annual daily flood peak with: drainage basin area, area of lakes and swamps, river channel slope and length, proportion of annual maximum floods occurring in the March to May period and the March 31 median snowpack depth.

APPENDIX B

IMPACTS OF ALTERNATIVE GAUGING STRATEGIES

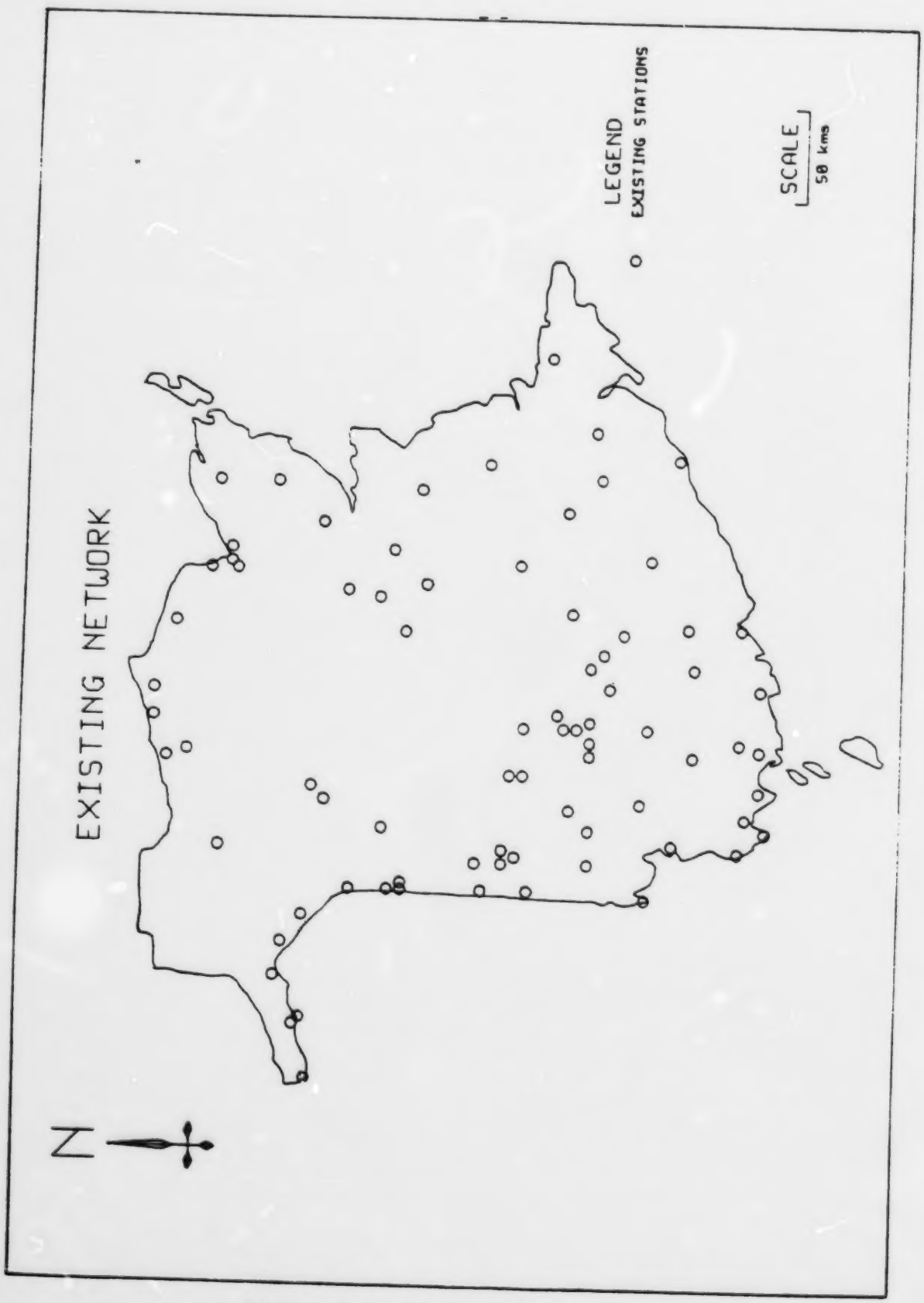


Figure B-1 Existing Network

TABLE B-1

SCENARIO SUMMARY : EXISTING NETWORK

(1) Scenario Assumption :	Existing Network (E)		
(2) Total Station Audit (S.A.) Points :	6455		
(3) Number of Existing Stations to be Kept :	85		
(4) Number of Stations to be Closed :	0	S.A. : 0	
(5) Number of Stations to be Added :	0	S.A. : 0	
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :	85	= $ 307,530	
(Change from Status Quo)	$ 0	= 0 %	

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED	Points	STATIONS TO BE CLOSED	Points
NONE		NONE	

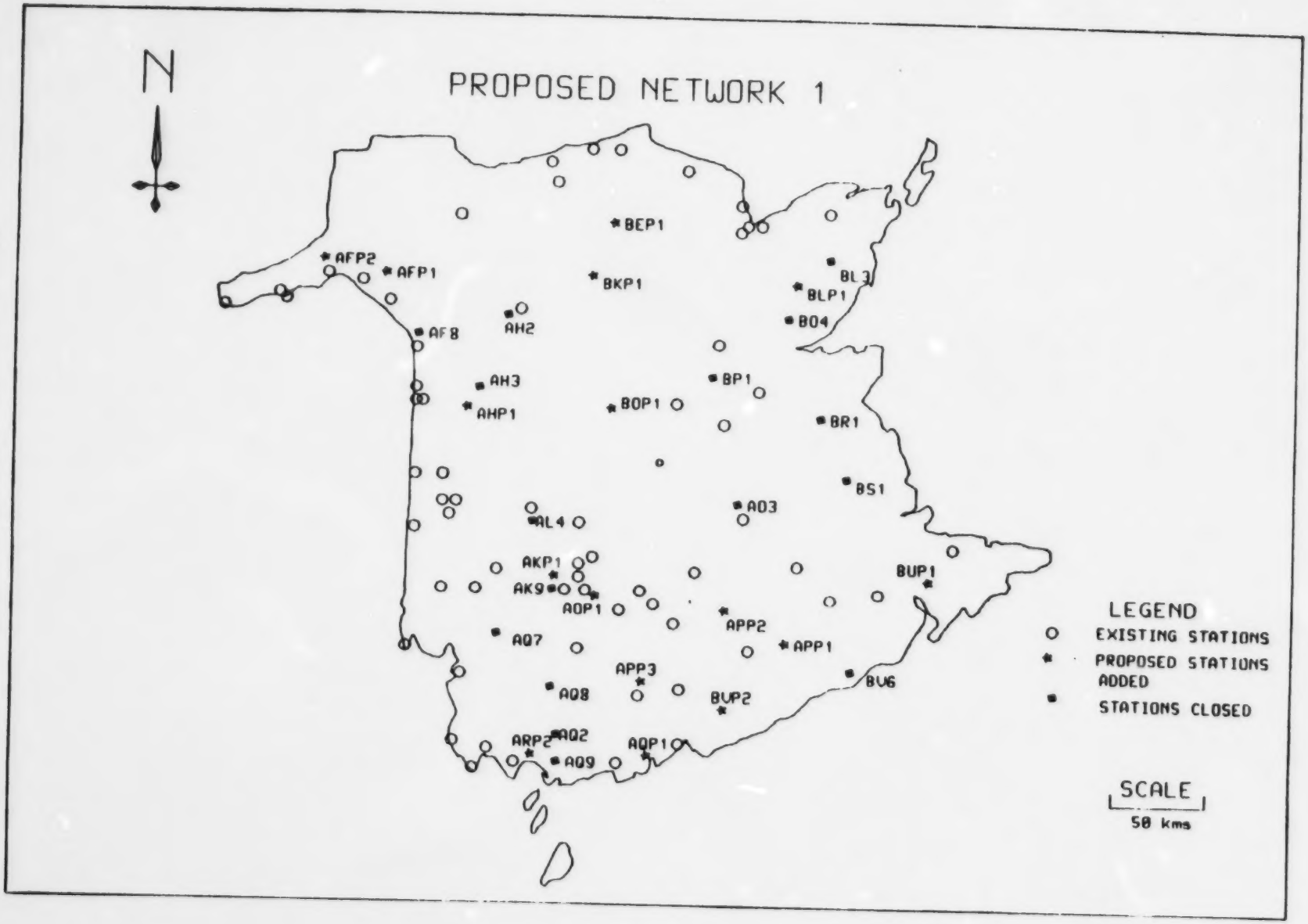


Figure B-2 Proposed Network 1

TABLE B-2

SCENARIO SUMMARY : PROPOSED NETWORK 1

(1) Scenario Assumption :	Existing and proposed stations prioritized by Station Audit scores at current (status quo) level of resources (P-1).		
(2) Total Station Audit (S.A.) Points :		6824 (+369)	
(3) Number of Existing Stations to be Kept :		69	
(4) Number of Stations to be Closed :		16	S.A. :(-844)
(5) Number of Stations to be Added :		16	S.A. :(+1213)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :		85	= $ 307,530
	(Change from Status Quo)	$ 0	= 0 %

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED

		Points
1APOP1N	TROUT CR	98
1AQOP1N	MUSQUASH R	87
1AHOP1N	ODELLACH R	85
1AFOP2N	IROQUOIS R	80
1AFOP1N	SIEGAS R	79
1BOOP1N	S BR RENOUS	79
1AKOP1N	KESWICK R	79
1AOOP1N	CORBETT BR	79
1BVOP2N	RATCLF BR	76
1BUOP1N	MEMRAMK R	72
1BLOP1N	UPR TRCDE	71
1BKOP1N	NEPESIG UPSTRM	70
1APOP3N	NEREPIS TRIB	66
1AFOP2N	L CANAAN	65
1BEOP1N	SE UPSALQ R	64
1AROP2N	BOCABEC R	64

STATIONS TO BE CLOSED

		Points
1AK009W	SJR AT MALTAQ	61
1AD003W	GRND LK NCSTLCR	59
1AQQ02R	MAGAG LMCR	59
1AQ007W	MAGAG LK	59
1AQ009W	L UTOPIA CHL	58
1BO004N	BARIBG R	56
1BL003N	BIG TRCDE R	55
1BS001N	COAL BR R	54
1BV006N	PT WOLF R	54
1AQ008N	PISKANEG R	53
1BP001N	LTL SWMIRAM R	51
1AH002R	TRQ RILBR	49
1AH003R	TRQ PLSRK	49
1AL004N	NRWS MTN BR	48
1BR001N	KOUCHIBGC R	46
1AF008W	SJR GRNDFLS	33

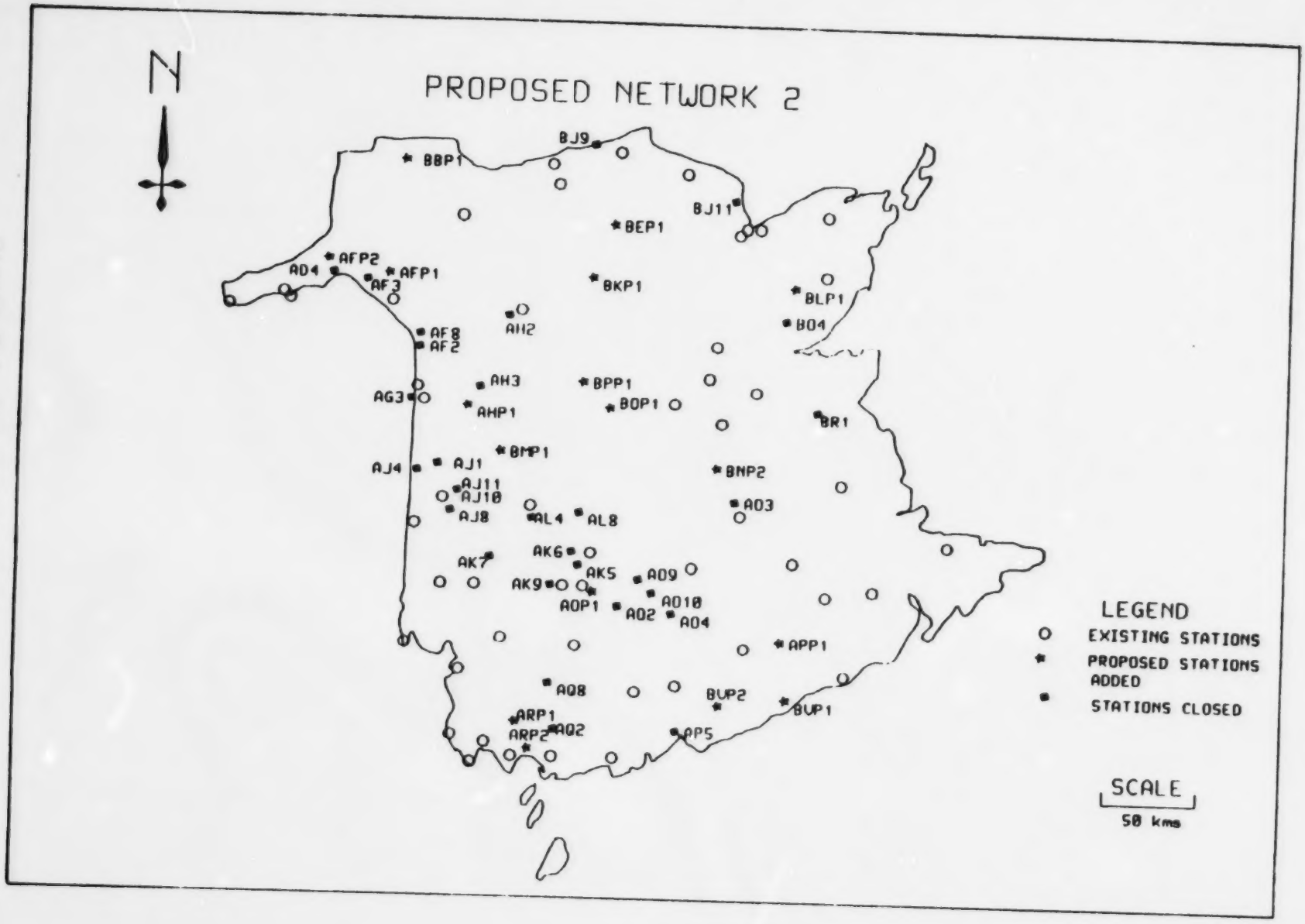


Figure B-3 Proposed Network 2

TABLE B-3

SCENARIO SUMMARY : PROPOSED NETWORK 2

(1) Scenario Assumption	: Minimum regional hydrology network, formal commitments, and index station requirements (P-2).
(2) Total Station Audit (S.A.) Points	: 5515 (-940)
(3) Number of Existing Stations to be Kept	: 55
(4) Number of Stations to be Closed	: 30 S.A. : (-1999)
(5) Number of Stations to be Added	: 17 S.A. : (+1137)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS	: 72 (-13) = $ 260,496
(Change from Status Quo)	: (- $ 47,034) = (-15 %)

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED

		Points
1AF0F1N	TROUT CR	98
1AH0F1N	ODELLACH R	85
1AF0F2N	IROQUOIS R	80
1AF0F1N	SIEGAS R	79
1B00F1N	S BR KENOUS	79
1A00F1N	CORBETT BR	78
1BV0F2N	RATCLF BR	76
1BL0F1N	UPR TRODE	71
1BK0F1N	NEPESIG UPST	70
1BE0F1N	SE UPSALQ R	64
1AR0F2N	ROCABEC R	64
1BB0F1N	KEDGEWICK R	58
1BF0F1N	TUADOOK R	57
1AR0F1N	DIGDEGUASH R	55
1BN0F2N	CAINS R	54
1BN0F1N	CAINS RDNST	48
1BV0F1N	BIG SAM R	41

STATIONS TO BE CLOSED

		Points
1BJ009R	WALKER BR	102
1BJ011N	NIGADOO R	92
1AF002R	SJR GRNDFLS	89
1AF005W	SJR ST JOH	86
1AD004W	SJR EDMUN	83
1AJ001R	SJR ESTFLORVL	83
1AF003R	GREEN RIV	80
1AK007N	NACKAWIC R	77
1AG003R	ARSTK RIV	76
1AJ008W	SJR HARTL	71
1AJ004N	BPKESISLE ST	70
1AJ011N	COLD STRM	67
1AD002W	SJR MGRVIL	66
1AJ010N	BLGAGUIM STR	65
1AD004W	JEMSEG R JEM	64
1AK005N	MRMASHSISROY	64
1AK006N	MRMASHSISFAR	64
1AD009N	BURP MILSTRM	63
1AL008N	NASHWKR STAN	62
1AD010W	FRNCH LK LKCN	62
1AK009W	SJR AT MACTAQ	61
1AD003W	GRD LK NCSLCR	59
1AD002R	MAGAG R LMCR	59
1B0004N	BARIBG R	56
1AD008N	PISKAHEG R	53
1AH002R	TRC RILBRK	49
1AH003R	TRD PLSRK	49
1AL004N	NRWS MTN BR	48
1BR001N	KOUCHIBGC R	46
1AF008W	SJR GRNDFLS	33

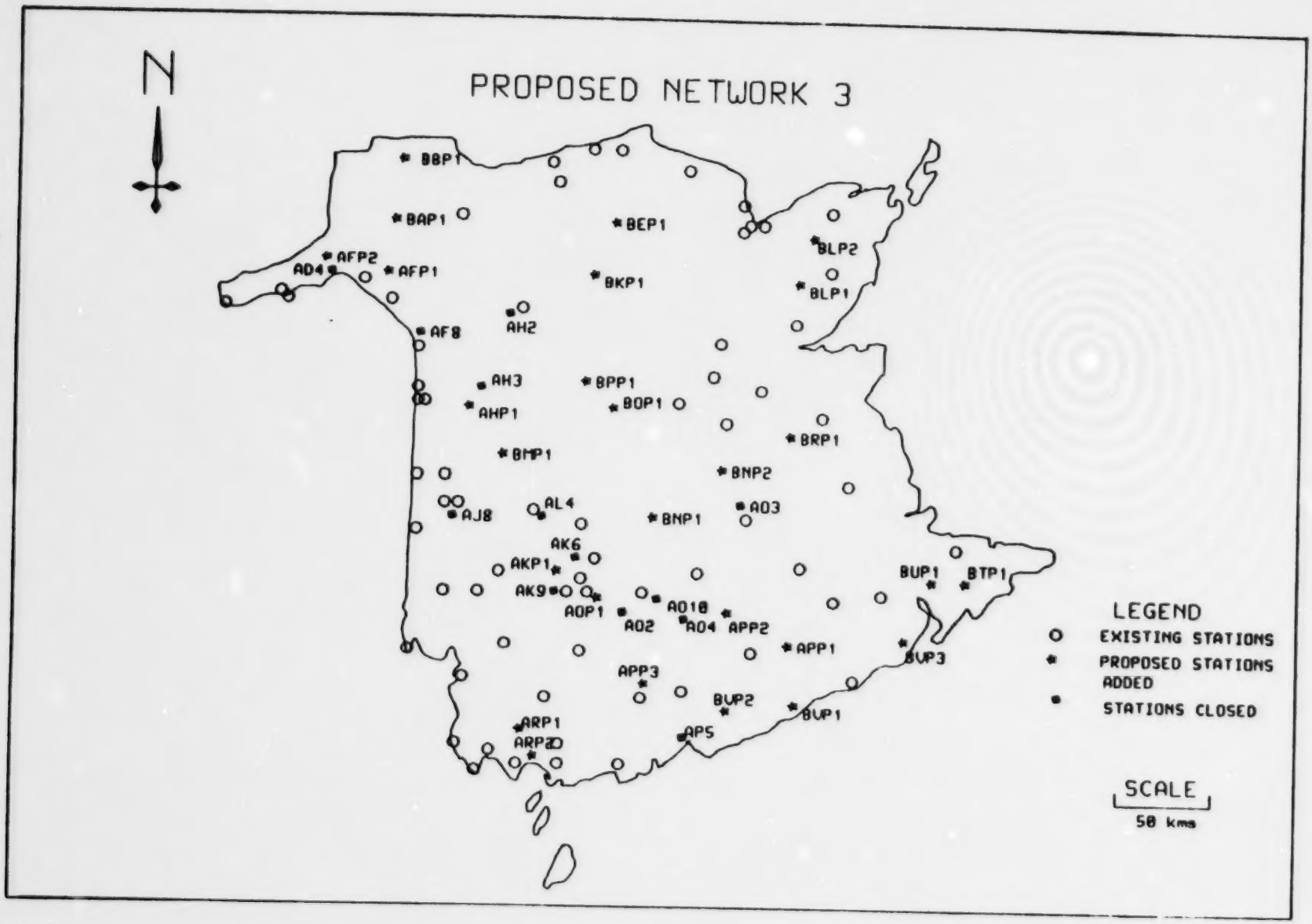


Figure B-4 Proposed Network 3

TABLE B-4

SCENARIO SUMMARY : PROPOSED NETWORK 3

(1) Scenario Assumption :	Optimal regional hydrology network , formal commitments, and index station requirements (P-3).		
(2) Total Station Audit (S.A.) Points :	7460 (+1005)		
(3) Number of Existing Stations to be Kept :	72		
(4) Number of Stations to be Closed :	13	S.A. :	(-759)
(5) Number of Stations to be Added :	27	S.A. :	(+1764)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :	99 (+14) = $ 358,182		
(Change from Status Quo) :	(+ $ 50,652) = (+ 17 %)		

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED		
		Points
1AFOP1N	TROUT CR	98
1AHOP1N	ODELLACH R	85
1AFOP2N	IROQUOIS R	80
1AFOP1N	SIEGAS R	79
1BOOP1N	S BR RENOUS	79
1AKOP1N	KESWICK R	79
1ADOP1N	CORBETT BR	78
1BVOP2N	RATCLF BR	76
1BUOP1N	MEMRAMK R	72
1BLOP1N	UPR TRCDE	71
1BKOP1N	NEPESIG UPST	70
1AFOP3N	NEREFIS TRIB	66
1APOP2N	L CANAAN	65
1BEOP1N	SE UPSALO R	64
1AROP2N	ROCABEC R	64
1BLOP2N	TABUSIN R	59
1BTOP1N	TANTRAM R	59
1BROP1N	KEDGEWICK R	58
1BFOP1N	TUADOOK R	57
1BAOP1N	GOUNAMITZ R	56
1BROP1N	KOUCH UPSTRM	55
1AROP1N	DIGDEGUASH R	55
1BNOP2N	CAINS R	54
1BMOP1N	SW MIRM FKS	48
1BNOP1N	CAINS RDNST	48
1BVOP3N	SHEPODY R	48
1BVOP1N	BIG SAM R	41

STATIONS TO BE CLOSED		
		Points
1AP005W	SJR ST JOH	86
1AD004W	SJR EDMUN	83
1AJ008W	SJR HARTL	71
1AD002W	SJR MGRVIL	66
1AD004W	JEMSEG R JEM	64
1AK006N	MBNASHSISFAR	64
1AD010W	FRNCH LK LKCN	62
1AK009W	SJR AT MACTAQ	61
1AD003W	GRD LK NCSLCR	59
1AH002R	TRC RILBRK	49
1AH003R	TRC PLSRK	49
1AL004N	NRWS MIN BR	48
1AF008W	SJR GRNDFLS	33

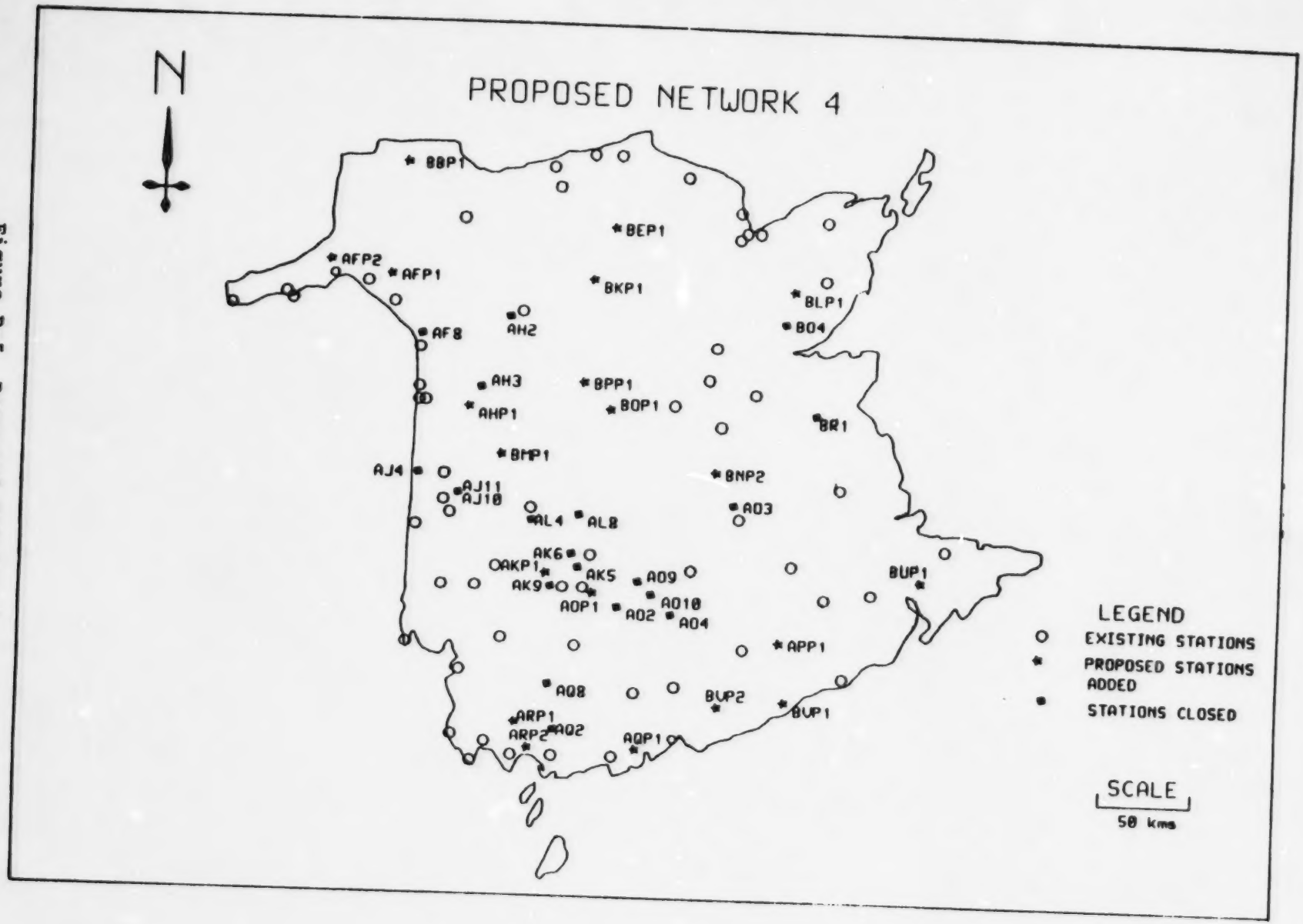


Figure B-5 Proposed Network 4

TABLE B-5

SCENARIO SUMMARY : PROPOSED NETWORK 4

(1) Scenario Assumption :	Minimum regional hydrology network, formal commitments, and index station requirements (i.e. same as P-2), as well as additional prioritized stations to current level of resources (P-4).		
(2) Total Station Audit (S.A.) Points :	6690 (+235)		
(3) Number of Existing Stations to be Kept :	65		
(4) Number of Stations to be Closed :	20	S.A. :	(-1160)
(5) Number of Stations to be Added :	20	S.A. :	(+1395)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :	85	=	$ 307,530
(Change from Status Quo)	$ 0	=	0 %

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED

		Points
1AF0P1N	TROUT CR	98
1AG0P1N	MUSQUASH R	87
1AH0P1N	ODELLACH R	85
1AF0P2N	IROQUOIS R	80
1AF0P1N	SIEGAS R	79
1BD0P1N	S BR RENOUS	79
1AK0P1N	KESWICK R	79
1AD0P1N	CORBETT BR	78
1BV0P2N	RATCLF BR	76
1BU0P1N	MEMRAMK R	72
1BL0P1N	UPR TRCDE	71
1BK0P1N	NEPESIG UPST	70
1BE0P1N	SE UPSALO R	64
1AR0P2N	BOCABEC R	64
1BB0P1N	KEDGEWICK R	58
1BF0P1N	TUADOOK R	57
1AR0P1N	DIGDEGUASH R	55
1BN0P2N	CAINS R	54
1BN0P1N	CAINS RDNST	48
1BV0P1N	BIG SAM R	41

STATIONS TO BE CLOSED

		Points
1AJ004N	BPRESISLE ST	70
1AJ011N	COLD STRM	67
1AD002W	SJR MGRVIL	66
1AJ010N	BEGAGUIM STR	65
1A0004W	JEMSEG R JEM	64
1AK005N	MBNASHSISRDY	64
1AK006N	MBNASHSISFAR	64
1AD009N	BURP MILSTRM	63
1AL008N	NASHWKR STAN	62
1AD010W	FRNCH LK LKCON	62
1AK009W	SJR AT MACTAQ	61
1AD003W	GRND LK NCSLCR	59
1AQ002R	MAGAG R LMCR	59
1BD004N	BARIBG R	56
1AD008N	PISKAHEG R	53
1AH002R	TBQ RILBRK	49
1AH003R	TBQ PLSRK	49
1AL004N	NRWS MTN BR	48
1BR001N	KOUCHIBGC R	46
1AF008W	SJR GRNDFLS	33

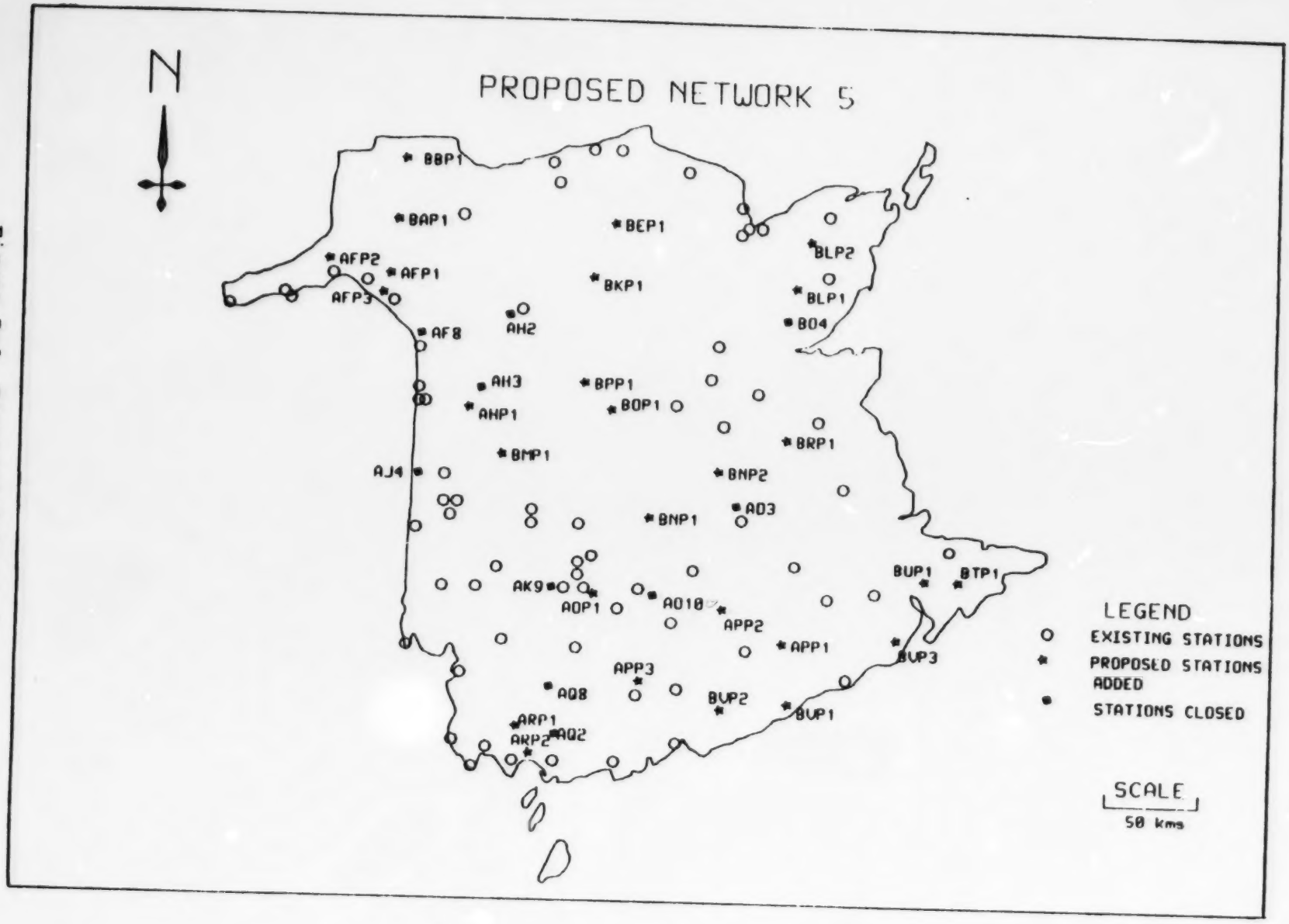


Figure B-6 Proposed Network 5

TABLE B-6

SCENARIO SUMMARY : PROPOSED NETWORK 5

(1) Scenario Assumption :	Minimum regional hydrology network, formal commitments, index station, and special regional hydrology needs (P-5).
(2) Total Station Audit (S.A.) Points :	7647 (+1192)
(3) Number of Existing Stations to be Kept :	75
(4) Number of Stations to be Closed :	10 S.A. : (-551)
(5) Number of Stations to be Added :	27 S.A. :(+1743)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :	102 (+17)= $ 369,036
(Change from Status Quo) :	(+ $ 61,506) = (+20 %)

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED

		Points
1APOP1N	TROUT CR	98
1AHOP1N	ODELLACH R	85
1AFOP2N	IROQUOIS R	80
1AFOP1N	SIEGAS R	79
1BDOP1N	S BR RENOUS	79
1ADOP1N	CORBETT BR	78
1BVOP2N	RATCLF BR	76
1BUOP1N	MEHRAHK R	72
1BLOP1N	UPR TRCDE	71
1BKOP1N	NEPESIG UPST	70
1APOP3N	NEREPIS TRIB	66
1APOP2N	L CANAAN	65
1BEOP1N	SE UPSALQ R	64
1AROP2N	BOCABEC R	64
1BLOP2N	TABUSIN R	59
1BTOP1N	TANTRAM R	59
1AFOP3N	QUISIBIS R	58
1BBOP1N	KEDGEWICK R	58
1BPOP1N	TUADOOK R	57
1BAOP1N	BOUNAMITZ R	56
1BROP1N	KOUCH UPSTR	55
1AROP1N	DIGDEGUASH R	55
1BNOP2N	CAINS R	54
1BMOP1N	SW MIRM FKS	48
1BNOP1N	CAINS RDWST	48
1BUOP3N	SHEPODY R	48
1BVOP1N	BIG SAM R	41

STATIONS TO BE CLOSED

		Points
1AJ004N	BPRESISLE ST	70
1AD010W	FRNCH LK LKCON	62
1AK009W	SJR AT MACTAQ	61
1AD003W	GRND LK NCSLCR	59
1AQ002R	MAGAG R LMCR	59
1BD004N	BARIBG R	56
1AD008N	PISKAHEG R	53
1AH002R	TBQ RILBRK	49
1AH003R	TBQ PLSRK	49
1AF008W	SJR GRNDFLS	33

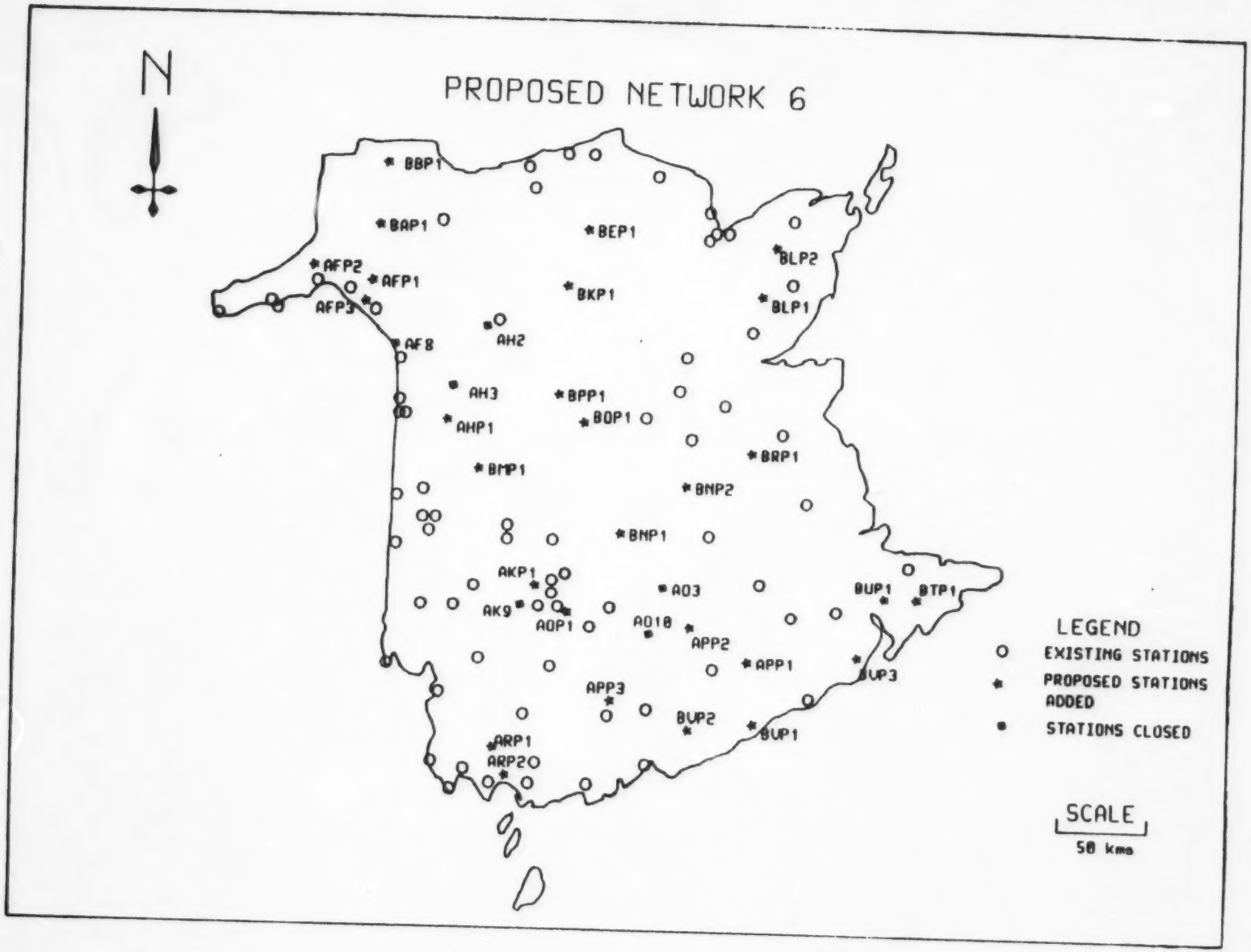


Figure B-7 Proposed Network 6

TABLE B-7

SCENARIO SUMMARY : PROPOSED NETWORK 6

(1) Scenario Assumption :	Optimal regional hydrology network ; formal committments;index stations;and special regional hydrology needs (P-6).
(2) Total Station Audit (S.A.) Points :	7964 (+1509)
(3) Number of Existing Stations to be Kept :	79
(4) Number of Stations to be Closed :	6 S.A. : (-313)
(5) Number of Stations to be Added :	28 S.A. :(+1822)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :	107 (+22) = $387,126
(Change from Status Quo) :	(+ $ 79,596) = (+ 26 %)

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED		Points
1AP0P1N	TROUT CR	98
1AH0P1N	ODELLACH R	85
1AF0P2N	IROQUOIS R	80
1AF0P1N	SIEGAS R	79
1RD0P1N	S BR RENOUS	79
1AK0P1N	KESWICK R	79
1AD0P1N	CORBETT BR	78
1BV0P2N	RATCLF BR	76
1BU0P1N	MEMRAMK R	72
1BL0P1N	UPR TRCDE	71
1BK0P1N	NEPESIG UPST	70
1AP0P3N	NEREPIS TRIB	66
1AP0P2N	L CANAAN	65
1BE0P1N	SE UPSALD R	64
1AR0P2N	ROCABEC R	64
1BL0P2N	TABUSIN R	59
1BT0P1N	TANTRAM R	59
1AF0P3N	QUISIBIS R	58
1BB0P1N	KEDGEWICK R	58
1BF0P1N	TUADOOK R	57
1BA0P1N	GOUNAMITZ R	56
1BR0P1N	KOUCH UPSTR	55
1AR0P1N	DIGDEGUASH R	55
1BN0P2N	CAINS R	54
1BM0P1N	SW MIRM FKS	48
1BN0P1N	CAINS RDNST	48
1BV0P3N	SHEPODY R	48
1BV0P1N	BIG SAM R	41

STATIONS TO BE CLOSED		Points
1AD010W	FRNCH LK LKCON	62
1AK009W	SJR AT MACTAQ	61
1AD003W	GRND LK MCSLCR	59
1AH002R	TBQ RILBRK	49
1AH003R	TBQ PLSRK	49
1AF00BW	SJR GRNDFLS	33

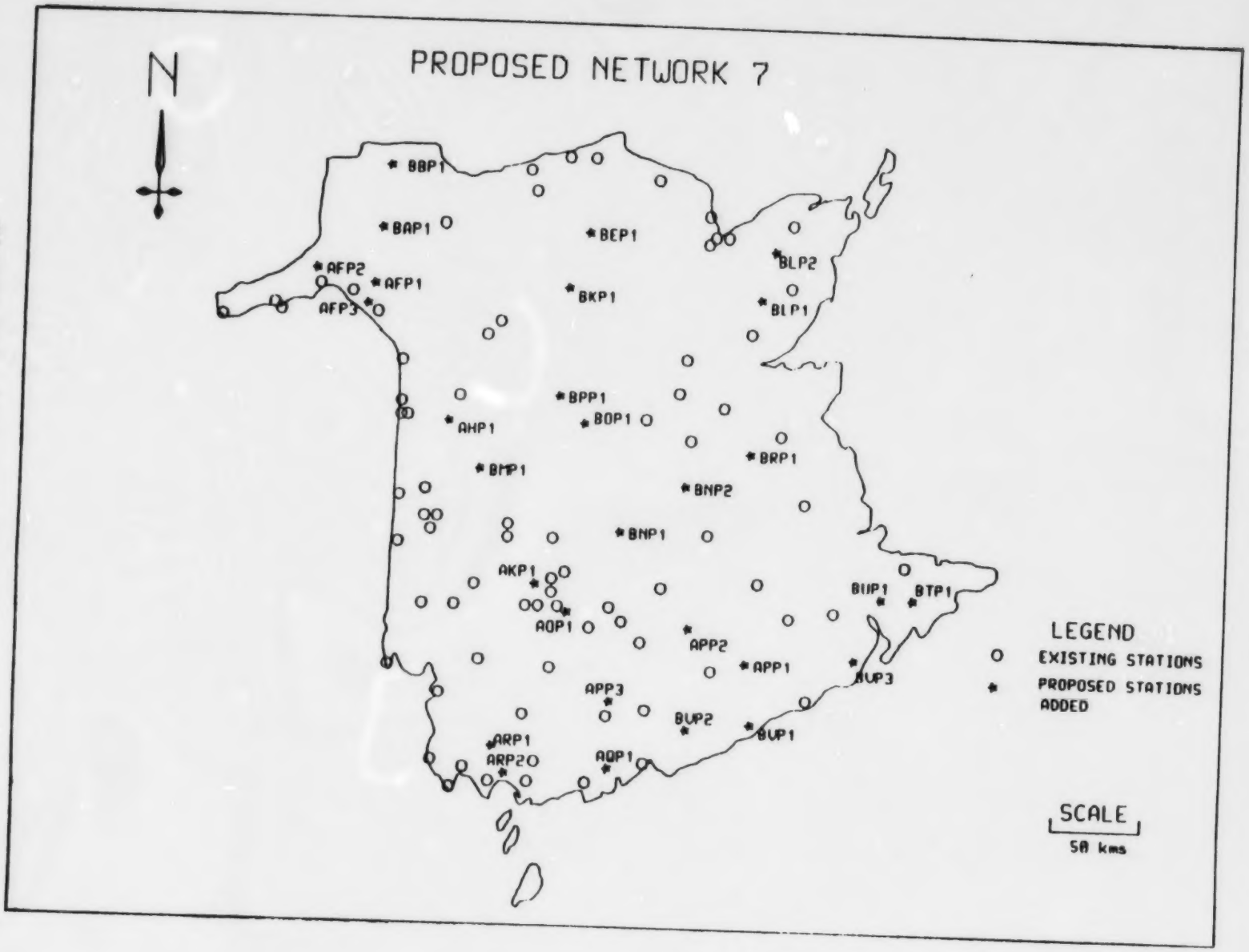


Figure B-8 Proposed Network 7

TABLE B-8

SCENARIO SUMMARY : PROPOSED NETWORK 7

(1) Scenario Assumption :	Optimal regional hydrology network and all other identified requirements (i.e.all existing and proposed stations).
(2) Total Station Audit (S.A.) Points :	8364 (+1909)
(3) Number of Existing Stations to be Kept :	85
(4) Number of Stations to be Closed :	0 S.A. : 0
(5) Number of Stations to be Added :	29 S.A. : (+1909)
(6) TOTAL COST = $ 3618 X TOTAL STATIONS :	114 (+29) = $ 412,452
(Change from Status Quo) :	(+ $ 104,922) = (+34 %)

IMPACT OF PROPOSED SCENARIO

STATIONS TO BE ADDED		Points
1AFOF1N	TROUT CR	98
1AGOF1N	MUSQUASH R	87
1AHOF1N	ODELLACH R	85
1AFOF2N	IROQUOIS R	80
1AFOF1N	SIEGAS R	79
1BGOF1N	S BR RENOUS	79
1AKOF1N	KESWICK R	79
1AGOF1N	CORBETT BR	78
1BVOF2N	RATCLF BR	76
1BUOF1N	MEMRAMK R	72
1BLOF1N	UPR TRCDE	71
1BKOF1N	NEPESIG UPST	70
1AFOF3N	NEREFIS TRIB	66
1AFOF2N	L CANAAN	65
1BEOF1N	SE UPSALQ R	64
1AROF2N	BOCABEC R	64
1BLOF2N	TABUSIN R	59
1BTOF1N	TANTRAM R	59
1AFOF3N	QUISIBIS R	58
1BBOF1N	KEDGEWICK R	58
1BFOF1N	TUADOOK R	57
1BAOF1N	GOUNAMITZ R	56
1BROF1N	KOUCH UPSTR	55
1AROF1N	DIGDEGUASH R	55
1BNOF2N	CAINS R	54
1BMOF1N	SW MIRM FKS	48
1BNOF1N	CAINS RDWST	48
1BVOF3N	SHEPODY R	48
1BVOF1N	BIG SAM R	41

STATIONS TO BE CLOSED
NONE

APPENDIX C

LIST OF BACKGROUND REPORTS

Background Report No. 1, Assessment of User Needs.

Background Report No. 2, Delineation of Physiographic-Climatic Zones.

Background Report No. 3, Regional Hydrology and Data Transfer Methodologies.

Background Report No. 4, Selected Technological and Operational Issues.

In addition to this Principal Report, there is a Supplemental Report: The Existing Network

and

following this Principal Report, a brief, French-English Summary Report was produced.